Science Library
QE
F37
UNIVERSITY OF MICHIGAN
PR
FEB 9 1954
SCIENCE LIBRARY

Volume XIX JANUARY, 1954 Number 1

GEOPHYSICS

A Journal of General and Applied Geophysics

Published Quarterly by the
Society of Exploration Geophysicists

CONTENTS

Regionals, Residuals, and Structures	*L. L. Nettleton*	1
A Theory for the Regional Correction of Potential Field Data	*Fraser S. Grant*	23
Some Geometrical Properties of Residual Maps	*Charles A. Swartz*	46
A Note on Downward Continuation of Gravity	*César A. Trejo*	71
The Correlation Between pre-Cambrian Rock Densities and Bouguer Gravity Anomalies near Parry Sound, Ontario	*C. H. G. Oldham*	76
Gravity Maxima Corresponding with Sedimentary Basins	*Rodolfo Martin*	89
Gravity Case History: Dawn No. 156 Pool, Ontario	*Richard A. Pohly*	95
Seismic Recording on Magnetic Tape	*G. B. Loper and R. R. Pittman*	104
The Gulf Airborne Magnetic Gradiometer	*W. E. Wickerham*	116
Exploration History (Prior to the Cotton Valley Discovery) of the Ruston Field, Lincoln Parish, Louisiana	*J. Ryan Walker*	124
A Message from the President	*Roy L. Lay*	139
Style Guide for *Geophysics*	*Milton B. Dobrin*	141
Introducing the Associate Editors of *Geophysics*		154
Patents		156
Reviews		163
Publications Received		170
Discussions and Communications		171
Memorial		
William Neal Hostetter		172
Robert Lee McLaren		173
Marcel Schlumberger		175
Contributors		177
Society Round Table		180
Committees		180
Membership Applications Approved for Publication		182
Announcements		185
Personal Items		186
Proposed Amendments to the By-Laws of the Society		188
Announcement of Program, 24th Annual Meeting		189

THE PERFECT COMBINATION TO A SUCCESSFUL SURVEY . . .

A seismographic company must be strong in every department of its organization, if it's going to give clients successful surveys. The combination must be "right."

That's why NATIONAL dwells so consciously — and conscientiously — upon every phase of exploration and interpretation before preparing the final seismic report.

This attention to detail shows up in the high percentage of successes with which the name NATIONAL has been associated over the past 18 years.

National GEOPHYSICAL COMPANY, INC.

GENERAL OFFICES
Dallas, Texas

FIELD OFFICES
Denver Houston
Dickinson, N. D.

NATIONAL GEOPHYSICAL COMPANY OF CANADA, LTD.
Calgary, Alberta

LEADING THE FIELD OF SEISMIC EXPLORATION

GEOPHYSICS

Published by the Society of Exploration Geophysicists

Printed in the U.S.A. by George Banta Publishing Company, Menasha, Wisconsin. Entered as second class matter September 7, 1938 at the post office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at the special rate of postage provided for in the Act of February 28, 1925, embodied in paragraph 4, Section 538, P. L. & R., authorized March 19, 1941. Copyright 1954 by the Society of Exploration Geophysicists.

EDITOR

MILTON B. DOBRIN, Magnolia Petroleum Co., P.O. Box 900, Dallas, Texas.

ASSOCIATE EDITORS

NORMAN RICKER, The Carter Oil Co., P.O. Box 801, Tusla Oklahoma.
Seismic Theory and Funadmentals

L. Y. FAUST, Amerada Petroleum Corp., P.O. Box 2040, Tulsa, Oklahoma.
Seismic Techniques and Operations

THOMAS A. ELKINS, Gulf Research and Development Co., P.O. Box 2038, Pittsburgh, Pa.
Gravity Prospecting

VICTOR V. VACQUIER, New Mexico Institute of Mining and Technology, Socorro, N.M.
Magnetic Prospecting

IRWIN ROMAN, Geophysics Branch, U. S. Geological Survey, Washington, D.C.
Electrical Prospecting

GENERAL INFORMATION

As the official publication of the Society of Exploration Geophysicists, GEOPHYSICS is sent to all members of the Society in good standing. For non-members and organizations, the subscription rate is $9.00 per year in the United States and its possessions and $9.50 per year in all other countries. The price of a single copy is $3.00 during the year of publication and $2.00 thereafter. For foreign postage 20¢ per copy should be added. Members of the Society can get the single copies at half-price (except for postage). Subscription and single-copy orders should be addressed to the Business Office of the Society, 624 S. Cheyenne, Tulsa 3, Oklahoma. A list of available back issues can be obtained from the Business Manager, Colin C. Campbell.

Claims for non-receipt of preceding numbers of GEOPHYSICS must be sent to the Business Manager within three months of the date of publication in order to be filled gratis. Delivery outside of the United States is not guaranteed.

Rates for advertising will be furnished by the Business Manager upon request.

MANUSCRIPTS

All manuscripts submitted for publication in GEOPHYSICS should, with the exceptions specified below, be sent directly to the Editor at the address given above. In addition to technical papers, the Editor welcomes notes, discussions of papers published in earlier issues and letters to the Editor. Announcements, news items, and personal items of interest to the Society's membership are published in the Society Round Table and should be submitted to the Business Manager. Reviews of geophysical literature published outside this journal should be submitted to the Chairman of the Standing Committee on Reviews, Dr. N. C. Steenland, Gravity Meter Exploration Co., 340 Esperson Bldg., Houston, Texas.

Instructions and recommendations regarding the form of manuscript material for GEOPHYSICS may be found in a paper by M. B. Dobrin in the January, 1954 issue (Volume XIX, No. 1, p. 141-153). This paper offers suggestions regarding the form for the typescript and illustrations, figure captions, headings, literature citations, footnotes, mathematical material, etc. It also specifies certain rules on capitalization, punctuation, abbreviations, etc. Reprints of this paper can be obtained from the Business Manager upon request.

Each manuscript submitted for publication will be examined by the Editor, who may forward it for evaluation to an Associate Editor and/or referees who are well informed in the field covered by the paper. The final decision as to acceptance of the paper will be communicated to the author as promptly as possible.

Papers submitted to the Society for publication shall be regarded as no longer confidential. Responsibility for all statements and opinions in GEOPHYSICS must be assumed by the individual authors.

REPRINTING OF MATERIAL FROM GEOPHYSICS

The right to reprint abstracts and short portions (not more than one page) of papers, discussions, or notes in GEOPHYSICS is granted on the express condition that reference be made to the source of such material. Longer text excerpts and illustrations from GEOPHYSICS may not be reproduced without the written permission of the Editor.

Society of Exploration Geophysicists

The Society of Petroleum Geophysicists was organized in 1930 at Houston, Texas. In 1936, the Society approved the change in name to the Society of Exploration Geophysicists, to indicate the close association of the aims and objects of the Society with the newly recognized primary function of Exploration, which had recently been recognized by the petroleum industry as being on a par with Production, Transportation, Refining, and Marketing.

AIMS AND OBJECTS

The Society functions for the promotion of the science of geophysics as it is related to petroleum geology and the production of oil and gas and associated minerals, to mining geology, and to the maintenance of a high professional standard among its members. Among the methods of accomplishing these objectives is the publication of papers, discussions, and communications of interest to the membership.

COUNCIL

OFFICERS

ROY L. LAY, The Texas Company, Box 2332, Houston, Tex. PRESIDENT

KARL DYK, Stanolind Oil and Gas Company, Box 591, Tulsa, Okla. VICE-PRESIDENT

BART W. SORGE, United Geophysical Company, Inc., Box M, Pasadena 15, Calif. SECRETARY-TREASURER

MILTON B. DOBRIN, Magnolia Petroleum Company, Box 900, Dallas, Tex. EDITOR

CURTIS H. JOHNSON, Geophysical Service, Inc., 5900 Lemmon Ave., Dallas 9, Texas PAST PRESIDENT

SIGMUND HAMMER, Gulf Research and Development Co., Drawer 2038, Pittsburgh 30, Pa. PRIOR PAST PRESIDENT

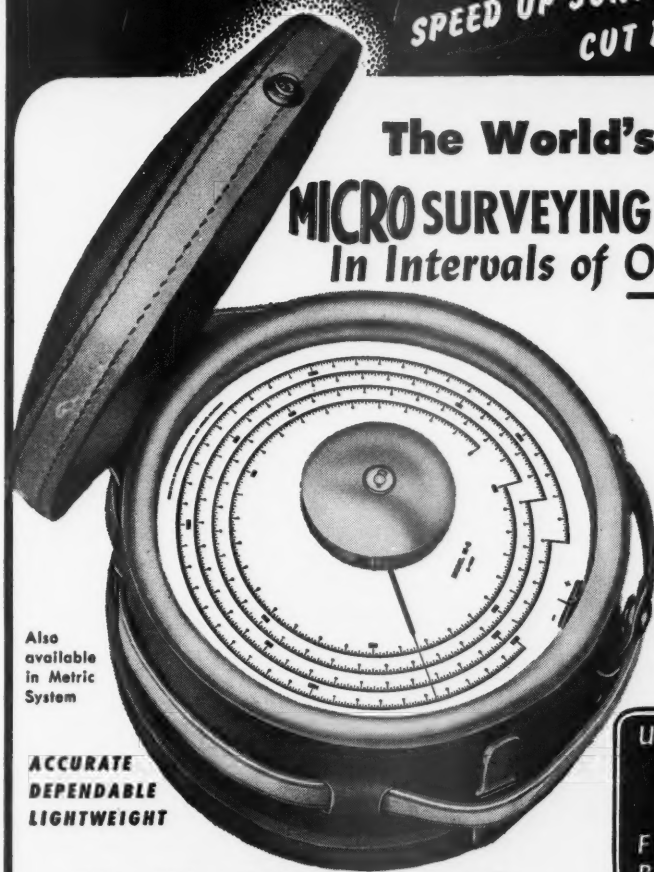
DISTRICT REPRESENTATIVES

Ark-La-Tex Geophysical Society: Richard Brewer and R. B. Baum
Canadian Society of Exploration Geophysicists: H. M. Houghton
Casper Geophysical Society: to be elected
Dallas Geophysical Society: D. R. Dobyns and J. P. Woods
Denver Geophysical Society: P. A. Weirich
Fort Worth Geophysical Society: R. W. Dudley
Geophysical Society of Oklahoma City: Arnold Bleyburg
Geophysical Society of Tulsa: E. V. McCollum, Reese H. Tucker and R. G. Piety
Pacific Coast Section: Milton Born and Harold C. Bemis
Permian Basin Geophysical Society: Fred Forward and W. L. Homan
SEG Houston Section: G. A. Berg and O. B. Manes

AMERICAN PAULIN SYSTEM

Surveying Altimeters

SPEED UP SURVEYS!
CUT DOWN COSTS!



The World's Finest...

MICRO SURVEYING ALTIMETER
In Intervals of ONE FOOT!

MODEL M-1 . . . Range 6,000 feet (—1000′ to+ 5000′) in intervals of 1′

MODEL M-2 . . . Range 10,000 feet (0′ to 10,000′) in intervals of 2′

MODEL M-5 . . . Range 15,000 feet (0′ to 15,000′) in intervals of 5′

MODEL MM-1 . . . Range 5,000 meters (0 to 5,000 meters) in intervals of 1 meter

$300 EACH with leather case, Thermometer, Magnifier, and Operational Procedures.

Also available in Metric System

ACCURATE
DEPENDABLE
LIGHTWEIGHT

USE THE NEW
MICRO
BAROGRAPH
FOR MODERN
BASE CONTROL

The World's Standard...

TERRA SURVEYING ALTIMETER

MODEL SA-1 . . . Range 4,360 feet (—760′ to+ 3,600′) in intervals of 2′

MODEL SA-2 . . . Range 10,600 feet (—900′ to+ 9,700′) in intervals of 5′

MODEL SA-5 . . . Range 15,000 feet (—500′ to+ 14,500′) in intervals of 10′

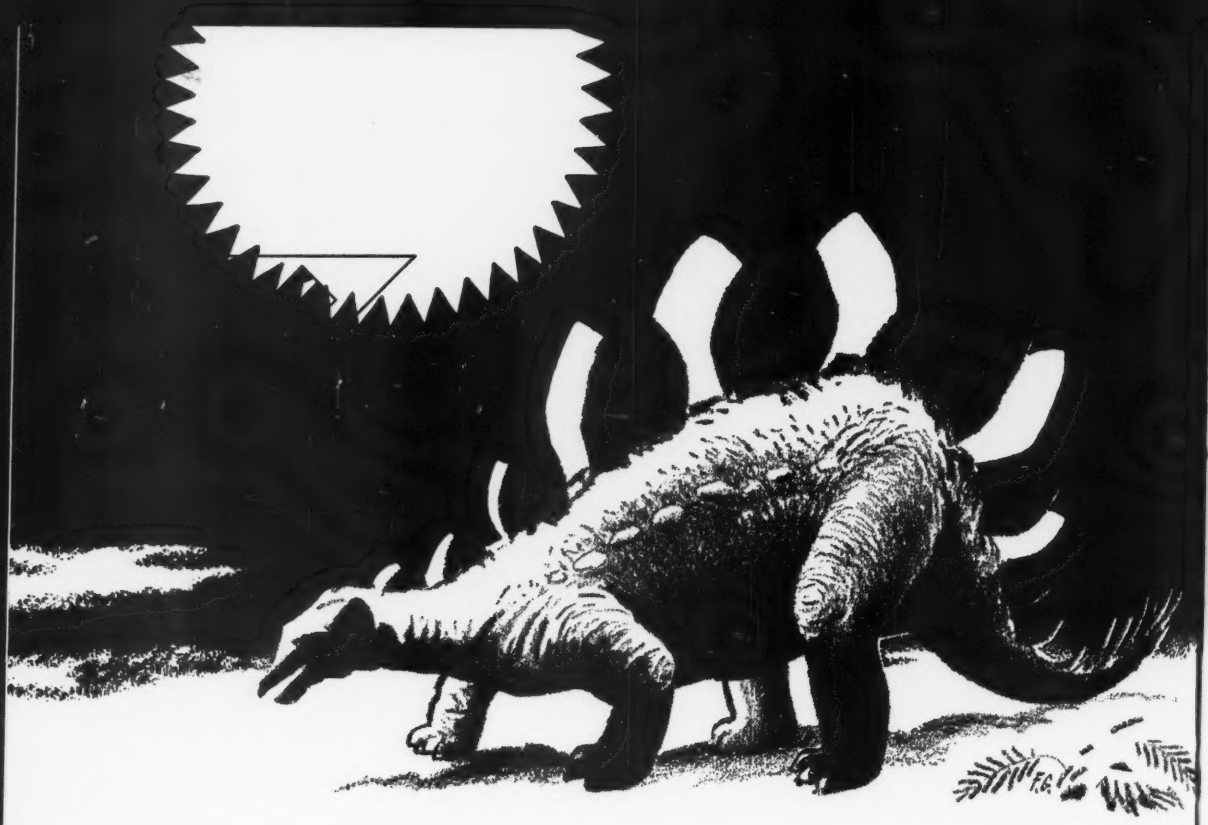
$200 EACH with leather case, Thermometer, Magnifier, and Operational Procedures.

Literature and Technical Publications Available on Request

MICRO **AMERICAN PAULIN SYSTEM** TERRA

1530 S. FLOWER • LOS ANGELES 15, CALIFORNIA, U.S.A.

MADE ENTIRELY IN U.S.A. BY THE
WORLD'S LEADING MANUFACTURER OF SURVEYING ALTIMETERS



THE WESTERN

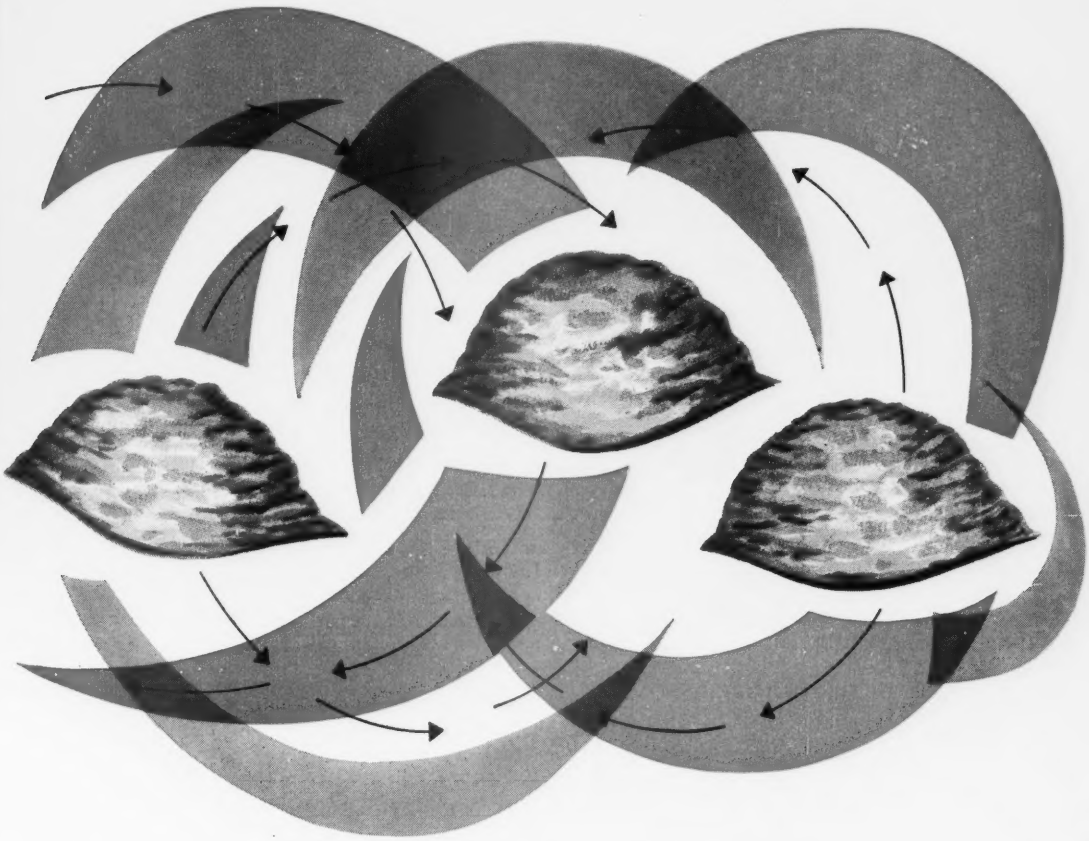
SUNDANCE* *Was Lost 125 Million Years Ago...*

BUT CENTURY CAN FIND IT FOR THE OIL OPERATOR

The Sundance formation was laid down 125 million years ago during the Jurassic Period. It was later "lost" under many other different geologic formations. Yet Century has the sound experience and research backed by skilled field and laboratory technicians using Century manufactured seismic equipment to find the Sundance or any other potential oil bearing formation. Both large and small operators in the United States and Canada have learned to depend on Century's accurate interpretation of subsurface data. You can depend on Century, too.

* The Sundance was formed during the Jurassic Period of the Mesozoic Era. Reptiles, like the brawny Stegosaurus, ruled the earth. Man had not appeared. Marine and land life flourished in the mild but occasionally arid climate. Strong crustal deformations characterized the late Jurassic Period.

CENTURY manufactures a complete line of standard and portable geophysical instruments



which shell is the bean under?

We wouldn't attempt to tell you, but when it comes to seismic surveys, we can remove a lot of the guess work. Like the shell game, each time a well is drilled you're taking a big gamble. But the gamble is less if the geophysical interpretation is correct. The wide experience of our interpretation specialists on the North American continent, application of the latest methods, and use of the most modern equipment, is Research's keynote for successful geophysical interpretations.

Research
EXPLORATIONS, INC.
HOUSTON, TEXAS

2136 WELCH, HOUSTON, TEXAS

AVAILABLE PUBLICATIONS OF

The American Association of Petroleum Geologists

1946 **Directory of Geological Material in North America.** By J. V. Howell and A. I. Levorsen. 112 pp. Pt. II, Aug. 1946, *Bull.* 5.5 x 8.5 inches. Paper 1.00

1947 **Comprehensive Index of the Publications of the A.A.P.G., 1917-1945.** Compiled by Daisy Winifred Heath. 603 pp. 6.75 x 9.50 inches. Cloth. **To members, $3.00** 4.00

1948 **Structure of Typical American Oil Fields.** Vol. III. McCoy Memorial Volume. 24 papers. 516 pp. 219 illus. Cloth. **To members, $3.50** 4.50

1948 **Appalachian Basin Ordovician Symposium.** From August, 1948, *Bulletin.* 264 pp. 72 illus. 6 x 9 inches. Cloth. **To members, $1.50** 2.00

1949 **Possible Future Oil Provinces of the United States and Canada.** 4th printing. From August, 1941, *Bulletin.* 154 pp., 83 figs. 6 x 9 inches. Paper. **To members, $1.00** 1.50

1949 **Problems of Petroleum Geology.** 2d printing. Originally published, 1934. 43 papers. 1,073 pp. 200 illus. 5.75 x 8.75 inches. Cloth. **To members, $4.00** .. 5.00

1950 **Structure of Typical American Oil Fields.** Vols. I and II. Symposium on Relation of Oil Accumulation to Structure. 3d printing. Originally published, 1929. Vol. I: 510 pp., 190 illus., 6 x 9 inches, cloth, $3.00. Vol. II: 750 pp., 235 illus., 6 x 9 inches, cloth, $4.00. Two volumes 7.00

1951 **Possible Future Petroleum Provinces of North America.** From February, 1951, *Bulletin.* 360 pp., 153 figs. 6 x 9 inches. Cloth. **To members, $2.50** ... 4.00

1951 **Contributions to the Study of Depositional Fabrics.** Rhythmically Deposited Triassic Limestones and Dolomites. By Bruno Sander (1936). Translated by Eleanora Bliss Knopf. 207 pp., 54 figs. 6 x 9 inches. Paper. **To members, $3.50** 4.00

1951 **Tectonic Map of the United States,** 4th printing. Originally published, 1944. Prepared under direction of National Research Council, Committee on Tectonics, Div. Geology and Geography. Scale, 1 inch = 40 miles. 7 colors. 2 sheets, each 40 x 50 inches. Folded, $2.00. In tube 2.50

1951 **Directory of Films and Slides of Possible Interest to Geologists** (2d ed.). Compiled under direction of Committee on Applications of Geology. 39 pp. 8.5 x 11 inches. Paper 0.50

1951 **Geology of California** (1933). By R. D. Reed. 355 pp., 58 figs., 26 tables. **Structural Evolution of Southern California** (1936). By R. D. Reed and J. S. Hollister. 157 pp., 57 figs., 14 photographs, 9-color tectonic map. Both offset reprinted. 5.5 x 8.5 inches. Clothbound together 6.00

1954 **Western Canada Sedimentary Basin.** Symposium, edited by Leslie M. Clark. 13 papers are new, 17 reprinted from the *Bulletin* of last 4 years, most of which have been revised. Cloth. **To members, $5.00** 6.00

Bulletin of The American Association of Petroleum Geologists. Official monthly publication. Each number, approximately 150 pages of articles, maps, discussions, reviews. Annual subscription, $18.00 (outside United States, $19.00). Descriptive price list of back numbers on request.

(Prices, postpaid. Write for discount to colleges and public libraries.)

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
BOX 979, TULSA 1, OKLAHOMA, U.S.A.

Check list of Du Pont products for seismic exploratory work

"Nitramon" S—Safest blasting agent ever devised for oil prospecting. Insensitive to ordinary blasting caps, fire or friction. Can only be detonated with a "Nitramon" S Primer . . . itself relatively insensitive. Packed in watertight metal containers that are threaded to facilitate assembling rigid charges of the desired strength.

"Nitramon" WW—Companion to "Nitramon" S for water work. Offers same safety features. Convenient. Economical. By far the most popular grade with offshore crews.

"Hi-Velocity" Gelatin 60%—Fills the need for deep-hole work, particularly where high water pressures and prolonged immersion are encountered.

Seismogel—Designed for use under less severe water conditions. An economical gelatin. Both "Hi-Velocity" and Seismogel are available with or without Du Pont "Fast-Couplers"... the quickest and simplest means for making up charges.

"SSS" Electric Blasting Caps—Dependable . . . accurate . . . highly static-resistant . . . improved plastic insulation prevents cracking in cold weather.

Seismograph Booster—An apparatus which provides additional insurance that the charge will detonate under adverse conditions of water depth or exposure periods. Boosts priming and frequently produces satisfactory shots where ordinary priming is inadequate.

CD-S Blasting Machine—Condenser discharge type. Charges at 500 volts; discharges at 1000 volts with condenser capacity of 300 microfarads. Rugged construction . . . for pattern shooting . . . combines very high capacity with maximum safety.

"Seismo-Writ"—Photo recording paper. (See Du Pont Seismo-Writ insert.)

The Du Pont representative serving your district will gladly give you complete information about any or all of these dependable products. Or write: E. I. du Pont de Nemours & Co. (Inc.), Explosives Department, Wilmington 98, Delaware.

See list of distributors ➡

Du Pont Distributors

Wherever your exploratory work may take you . . . there's a Du Pont Explosives distributor nearby, ready to meet your needs as they come up in the field. Keep the following list handy.

ALABAMA

Birmingham—E. I. du Pont de Nemours & Co., Brown-Marx Bldg.
Brewton—Dixie Dynamite Distributors, Inc.
Brewton—Southern Sales & Transp. Co.

ARIZONA

J. D. Buckley, Inc., Farmington, N. Mex.
E. I. du Pont de Nemours & Co., 922 Midland Savings Bldg., Denver, Colo.

ARKANSAS

E. I. du Pont de Nemours & Co., Joplin National Bank Bldg., Joplin, Mo.

CALIFORNIA

Bakersfield—Albert M. Clark
San Francisco, 4—E. I. du Pont de Nemours & Co., 111 Sutter Street.
Seattle, 4, Wash.—E. I. du Pont de Nemours & Co., Hoge Bldg.

COLORADO

Denver—J. D. Buckley, Inc., 1200 Hudson Street.
Denver—E. I. du Pont de Nemours & Co., 922 Midland Savings Bldg.

CONNECTICUT AND DELAWARE

E. I. du Pont de Nemours & Co., Empire State Bldg., New York, New York.

FLORIDA

Homestead—W. D. Horne Co.
Miami—Miami Dynamite Co.
Mulberry—S. E. McNeal
Ocala—Marion Hardware Co.

GEORGIA

E. I. du Pont de Nemours & Co., Brown-Marx Bldg., Birmingham, Ala.

IDAHO

E. I. du Pont de Nemours & Co., Hoge Bldg., Seattle, Wash.

ILLINOIS, INDIANA AND IOWA

Chicago—E. I. du Pont de Nemours & Co., 332 So. Michigan Avenue.

KANSAS

E. I. du Pont de Nemours & Co., Joplin National Bank Bldg., Joplin, Mo.

KENTUCKY

E. I. du Pont de Nemours & Co., 322 So. Michigan Ave., Chicago, Ill.

LOUISIANA

Alexandria—Dixie Dynamite Distributors, Inc.
Alexandria—Southern Sales & Transp. Co.
Alexandria—Sunshine Transfer Co.
Houma—Dixie Dynamite Distributors, Inc.
Houma—Southern Sales & Transp. Co.
Lafayette—Southern Sales & Transp. Co.
Monroe—Dixie Dynamite Distributors, Inc.
Shreveport—Southern Sales & Transp. Co.
New Orleans—T. Smith & Sons.

MAINE, MARYLAND AND MASSACHUSETTS

E. I. du Pont de Nemours & Co., Empire State Bldg., New York, New York.

MICHIGAN

Chicago, Ill.—E. I. du Pont de Nemours & Co., 332 So. Michigan Ave.
Duluth, Minn.—E. I. du Pont de Nemours & Co., 742 E. Superior St.

MINNESOTA

Duluth—E. I. du Pont de Nemours & Co., 742 E. Superior Street.

MISSISSIPPI

Brookhaven—Southern Sales & Trans. Co.
Hattiesburg—Dixie Dynamite Distributors, Inc.
Jackson—Dixie Dynamite Distributors, Inc.
Jackson—McGhee Motor Freight Lines.

MISSOURI

Joplin—E. I. du Pont de Nemours & Co., Joplin National Bank Bldg.

MONTANA

Miles City—Buckley Powder Co., Inc.
Roundup—Roundup Powder Co., Box 487
Wolf Point—Roundup Powder Co.

DU PONT SEISMIC

Serve all 48 States

NEBRASKA
E. I. du Pont de Nemours & Co., 922 Midland Savings Bldg., Denver, Colo.

NEVADA
Buckley Explosives of Wyoming, Inc., Vernal, Utah.
E. I. du Pont de Nemours & Co., 922 Midland Savings Bldg., Denver, Colo.

NEW HAMPSHIRE AND NEW JERSEY
E. I. du Pont de Nemours & Co., Empire State Bldg., New York, New York.

NEW MEXICO
Farmington—J. D. Buckley, Inc.
Hobbs—Thompson Powder Co., Inc., Box 505.

NEW YORK
E. I. du Pont de Nemours & Co., Empire State Bldg.

NORTH CAROLINA
E. I. du Pont de Nemours & Co., West Virginia Bldg., Huntington, W. Va.

NORTH DAKOTA
Bismarck—Roundup Powder Co.
Dickinson—Roundup Powder Co.
Williston—Roundup Powder Co.

OHIO
E. I. du Pont de Nemours & Co., Gulf Bldg., Pittsburgh, Penna.

OKLAHOMA
Oklahoma City—Southern Sales & Transp. Co.

OREGON
E. I. du Pont de Nemours & Co., Hoge Bldg., Seattle, Wash.

PENNSYLVANIA
Pittsburgh—E. I. du Pont de Nemours & Co., Gulf Bldg.

RHODE ISLAND
E. I. du Pont de Nemours & Co., Empire State Bldg., New York, New York.

SOUTH CAROLINA
E. I. du Pont de Nemours & Co., Brown-Marx Bldg., Birmingham, Ala.

SOUTH DAKOTA
Bismarck, N. Dak—Roundup Powder Co.
Miles City, Mont.—Buckley Powder Co., Inc.

TENNESSEE
E. I. du Pont de Nemours & Co., Brown-Marx Bldg., Birmingham, Ala.

TEXAS
Alice—Southern Sales & Transp. Co.
Big Lake—Thompson Powder Co., Inc.
Houston—Southern Sales & Transp. Co.
Lubbock—Thompson Powder Co., Inc.
Mineral Wells—Dallas Explosive Co.
Rosenberg—Mike Huber
Rosenberg—Southern Sales & Transp. Co.
San Antonio—Alamo Explosives Co.

UTAH
Vernal—Buckley Explosives of Wyo., Inc.

VERMONT
E. I. du Pont de Nemours & Co., Empire State Bldg., New York, New York.

VIRGINIA
E. I. du Pont de Nemours & Co., West Virginia Bldg., Huntington, W. Va.

WASHINGTON
Seattle—E. I. du Pont de Nemours & Co., Inc., Hoge Bldg.

WEST VIRGINIA
Huntington—E. I. du Pont de Nemours & Co., Inc., W. Virginia Bldg.

WYOMING
Casper—Buckley Explosives of Wyo., Inc.
Rock Springs—Buckley Explosives of Wyo., Inc.
Worland—Buckley Explosives of Wyo., Inc.

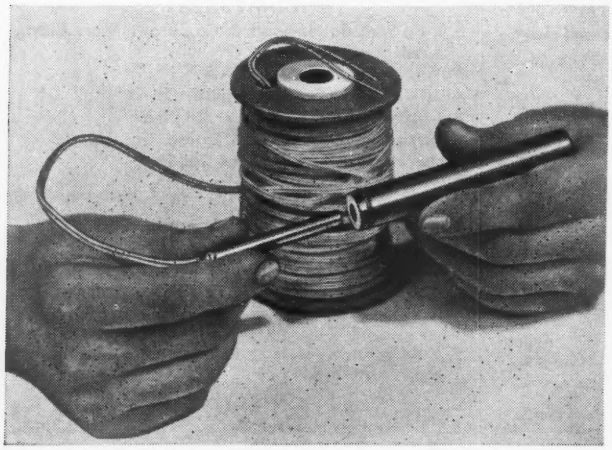
WISCONSIN
Duluth, Minn.—E. I. du Pont de Nemours & Co., Inc., 742 E. Superior St.
Chicago, Ill.—E. I. du Pont de Nemours & Co., Inc., 332 So. Michigan Ave.

Du Pont Seismic Products are widely used throughout the oil-prospecting industry. Ask the Du Pont Explosives representative in your district for complete information about these dependable products. E. I. du Pont de Nemours & Co. (Inc.), Explosives Department, Wilmington 98, Delaware.

DU PONT
REG. U.S. PAT. OFF.
PRODUCTS
BETTER THINGS FOR BETTER LIVING
. . . THROUGH CHEMISTRY

ATLAS EXPLOSIVES FOR SEISMIC PROSPECTING

Atlas Powder Company, Wilmington 99, Delaware

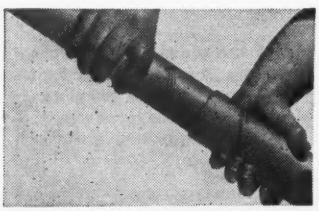


Giant Boosters Assist Detonation Under High Heads of Water

A new Atlas product, the Giant Booster, is used to initiate the detonation of explosives columns under the most difficult conditions. Giant Boosters are recommended for sleeper holes and use with high heads of water encountered in deep holes.

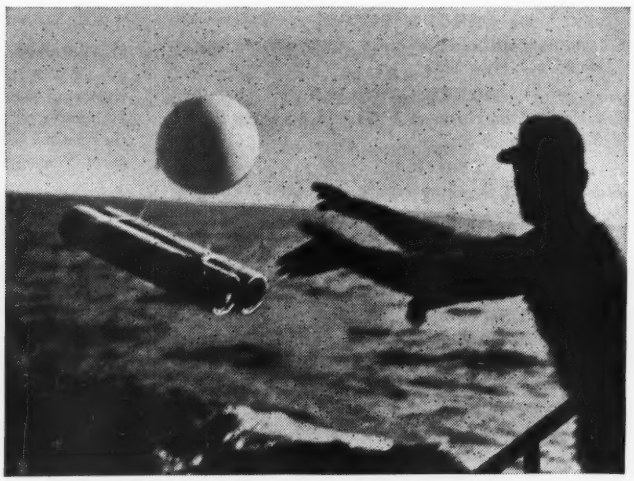
Staticmaster® Caps provide increased resistance to accidental detonation by static electricity

The new Staticmaster electric blasting caps are made with rubber plugs and are fully waterproof. The duplex insulation on No. 20 gauge copper leg wire is designed to withstand severe conditions of deep hole loading. Seismograph crews have found the spool assembly a great convenience in loading assembled explosives in deep holes.



Fast Loading with Twistite® Assembly

The Twistite Assembly is a fast coupling device which connects cartridges of explosives in a rigid column. This construction makes sturdy, continuous columns quick and easy to prepare. They will withstand the most severe loading conditions.



For off shore shooting, *Petronite is a new Atlas blasting agent developed especially for this type of work. It is packed in rigid containers and cannot be detonated without a special primer.*

Fieldmen prefer

the BRIGHTER MORE DURABLE EASY-TO-TIE

Flagging Tape

VISKON flagging tape stays bright, won't fade in any weather conditions. Available in brilliant red—orange—blue—yellow—and white. VISKON can be used wet or dry—doesn't "rope"—and does not become brittle in cold weather. Supplied on a handy core to loop right on your belt. Is non-toxic. Easy to write on. Standard put-up 1½ inches wide, 300 feet to a roll—other sizes available.

VISKON NONWOVEN FABRIC

. . . Another product for modern industry by

THE VISKING CORPORATION
NORTH LITTLE ROCK, ARKANSAS

THE VISKING CORPORATION, DEPT. GQ-1
P. O. BOX 72, North Little Rock, Ark.
Please send information on VISKON plus free sample swatch of each survey flagging tape color.

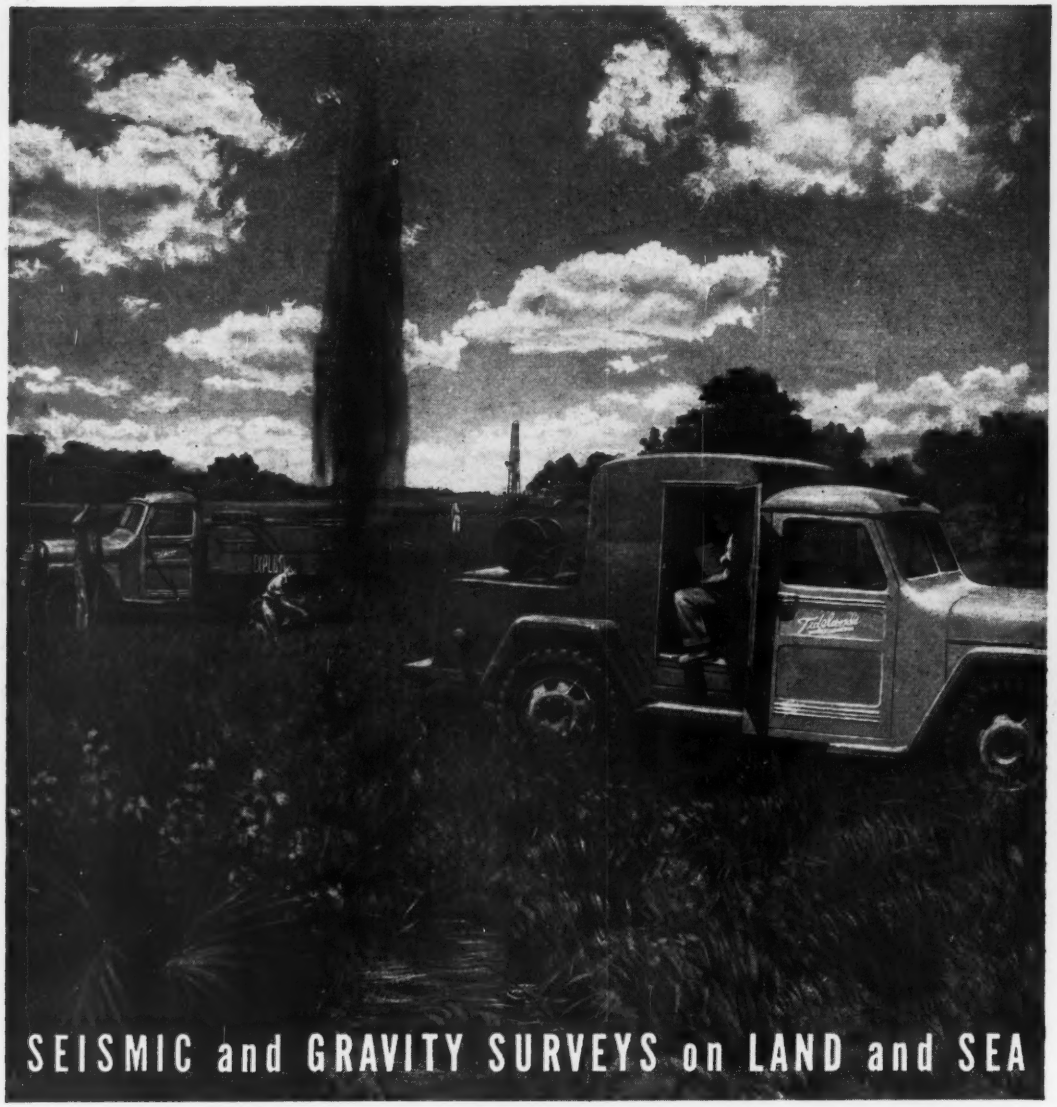
NAME_____

COMPANY_____

ADDRESS_____

CITY_____ ZONE____ STATE_____

NAME OF MY SUPPLIER_____



• DENSITY LOGS • SEISMIC AND GRAVITY INTERPRETATIONS

A complete service within the organization with the most modern equipment and highly-trained personnel

Tidelands
EXPLORATION CO. HOUSTON, TEXAS

2626 WESTHEIMER LYnchburg 3781

"SUCCESSFUL EXPLORATION *demands specialized instrumentation"*

Let SIE design custom-built seismograph instruments to meet your special requirements

Bid the good old days farewell, the easy prospects have all been worked. Today — geophysicists and instrument-builder's reputations are established on the tough ones. These areas demand that the geophysicist and instrument manufacturer work hand-in-hand to develop the new techniques and equipment required for successful exploration.

To meet this demand, SIE offers the experience gained in furnishing the geophysical industry with more than 200 complete seismograph systems. This experience insures that your special instrumentation requirements are met by the most complete development facilities in the industry, backed by acknowledged leadership in the construction of rugged and dependable seismic equipment.

Today — more than 100 of the world's leading geophysical organizations agree: "IT PAYS TO LET SIE BE YOUR LAB!"

SIE

See other side

SOUTHWESTERN INDUSTRIAL ELECTRONICS CO.

2831 POST OAK ROAD • P. O. BOX 13058 • HOUSTON 19, TEXAS

NOW SIE PRO-11 Oscillograph

is available with . . .

50 GALVANOMETERS

10 INCH PAPER

FEATURES

Galvanometers — Have a natural frequency of 125 cycles per second and a focal length of 11 inches. Other frequencies available on special order.

Viewing Screen — A portion of the light reflected by each galvanometer is cast on the ground glass viewing screen in the same attitude and sequence they have on the recording surface.

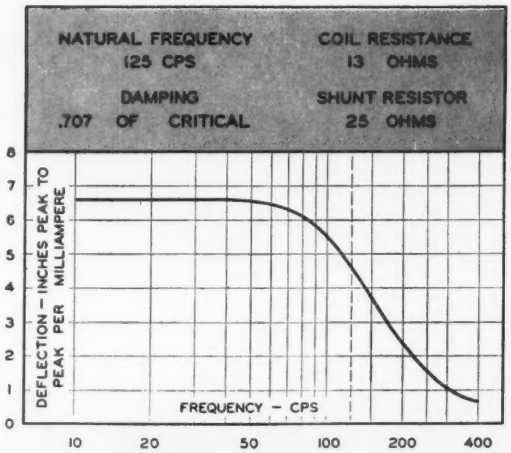
Light Sources — Galvanometer and timing system lamps are available commercially. Adjustable resistors allow control of contrast between timing and trace up to 50 indications.

Timing System — The shock-mounted bimetallic timing fork is temperature compensated. Frequency of the fork circuit output voltage is constant within one part in 100,000. Lines of different intensity appear on the record at 1/10, 1/20, and 1/100 second intervals.

Paper Drive — A 12-volt, governor controlled motor with integral reduction gear drives the positive-drive paper feed rollers at a speed range of 10 to 15 inches per second. Other ranges available on order.

Storage Magazine — The magazine accommodates 150 feet of conventional ten-inch paper; however, 200 feet of thin paper can be loaded.

Record Magazine — The record magazine is constructed of black anodized aluminum and easily accommodates a record 20 feet long.



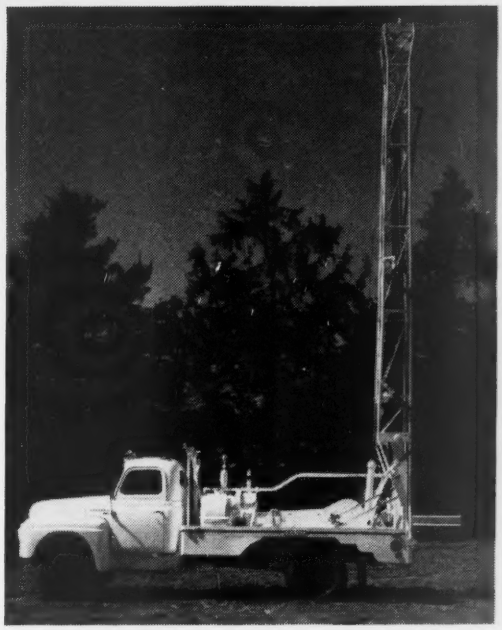
The SIE 50-Element PRO-11 Recording Oscillograph fills the industry requirement for a light weight, compact and reliable unit which affords full recording flexibility. Its modern design facilitates dual recording, mixed and unmixed presentation and multi-channel recording applications. The PRO-11-10 can be used successfully with many different models and types of equipment. Its 44-lb. weight and water-tight construction insure full portability and long life. Contact SIE today for delivery and price information.

SOUTHWESTERN INDUSTRIAL ELECTRONICS CO.

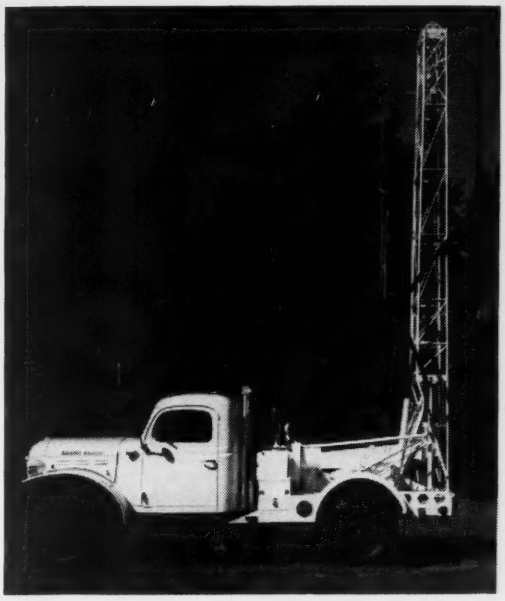
2831 POST OAK ROAD • P. O. BOX 13058 • HOUSTON 19, TEXAS

YOU JUST CAN'T BEAT...

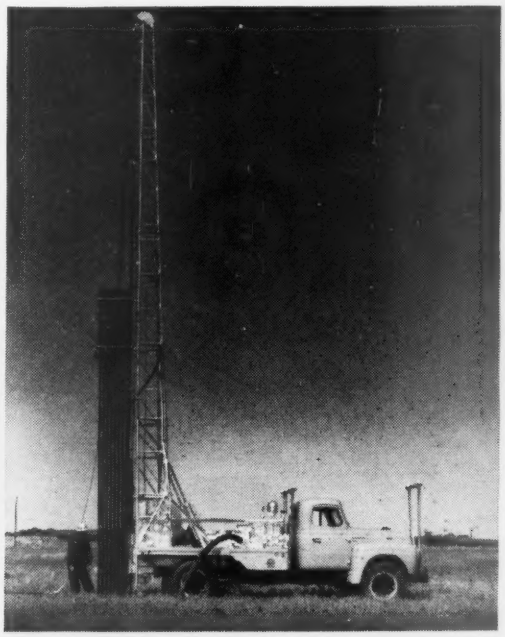
a Failing rig!



THE FAILING CFD-1 Holemaster is designed especially for fast shot hole drilling. Its rated capacity is 1,000 feet using 2⅜" drill pipe.



THE LIGHT WEIGHT CFD-2 Holemaster is the ideal rig for swamp areas or wherever transportation is a problem. For fast shot hole drilling to 350 feet using 2⅜" drill pipe.



THE FAILING 1500 Holemaster is an all-purpose rig. It is used for every type of oil exploration as well as for shallow production. Its rated capacity is 1,500 feet using 2⅜" drill pipe.

FAILING "EXTRAS"

When you buy a FAILING rig you get more than a piece of fine equipment. You get such FAILING extras as:

1. Service by FAILING-trained, field-experienced engineers.
2. Emergency service on replacement parts in every part of the country.
3. Constant research by FAILING engineers on all drilling problems.
4. Unconditional guarantee on all FAILING-made equipment.

FAILING rigs are manufactured under rigid mechanical requirements. You just can't beat a FAILING.

GEORGE E. FAILING COMPANY

George E. Failing Company

A SUBSIDIARY OF WESTINGHOUSE AIR BRAKE CO.

ENID, OKLAHOMA, U.S.A.

engineered
seismic surveys

6111 Maple Avenue • Dallas, Texas

R. D. Arnett C. G. McBurney J. H. Pernell

Why the trend is to Electro-Tech instruments + equipment

Electro-Tech

MANUFACTURES AND MARKETS ITS OWN COMPLETE LINE OF SEISMIC EQUIPMENT:

- AMPLIFIERS
- OSCILLOGRAPHS
- DETECTORS
- CABLES
- GALVANOMETERS
- ACCESSORIES

GEOPHYSICS ADVERTISERS

Advanced Exploration Company 53
Aero Service Corporation 70
Am. Assoc. of Pet. Geol. *insert facing page 5*
American Institute of Physics 26
American Paulin System 3
Ampex Corporation 28
Atlas Powder Company 8

Wm. M. Barret, Inc. 35
Braithwaite & Caldwell 37

Canadian Aero Service Ltd. 25
Century Geophysical Corporation 4
Continental Geophysical Company 80

E. J. DuPont—Explosives .....5, 6 & 7
E. J. DuPont—Photo Products 49

European Assoc. of Expl. Geoph. 40
Eastman Kodak Company 27
Economic Geology 38
Electro-Technical Labs. 13

George E. Failing Company 11
General Geophysical Company 47
Geophysical Service Inc. .....*4th cover*
Geophysical Society of Tulsa 34
Gravity Meter Exploration Company ... 16
Griffin Tank & Welding Service 81

The Haloid Company 60
Herb J. Hawthorne, Inc. 66
Heiland Research Corporation 63
Hercules Powder Company 57
Houston Technical Labs. 56

Independent Exploration Company 46

Joy Manufacturing Company 32

Klaus Exploration Company 43
Koenig Iron Works 39

Lane-Wells Company 52

MacClatchie Mfg. Company 44
E. V. McCollum & Company .....36 & 79
R. S. McCauley 38
Mayes-Bevan Company 41
Midwestern Geophysical Lab. 29
Mission Manufacturing Company 42

National Geophysical Company ....*2nd Cover*
North American Geophysical Co. 30

Offshore Exploration Group 68

Petty Geophysical Engg. Co. 67
Princeton University Press 54

Robert H. Ray Company 62
Rayflex Exploration Company 48
Reliable Geophysical Company 71
Republic Exploration Company 31
Research Explorations, Inc. .....
.....*insert facing page 4*
Rogers Geophysical Company 58
Ruska Instrument Corporation 55

Schlumberger Well Surveying Corp. ... 59
Scott-Rice Company 38
Seismic Analysis, Inc. 74
Seismic Engineering Company 12
Seismic Explorations Inc. 61
Seismograph Service Corporation ..*3rd cover*
Southern Geophysical Company 78
S.W. Industrial Electronics Company ..
.....*insert facing page 10*
Spang & Company 38
States Exploration Company 82

Technical Instrument Company ....*76 & 77*
Texas Instruments Inc. 64
Texas Seismograph Company 26
Tex-Tube Supply Company 72
Tidelands Exploration Company 10
Triad Transformer Mfg. Co. 45
Trija Publishing Company 34

United Geophysical Company 73

Vector Manufacturing Company 75
The Visking Corporation 9

Wallace & Tiernan Products 15
Lew Wenzel & Company .....50 & 51
Western Geophysical Company 65

Professional Directory begins on page .. 17

Geophysical Societies .....24 & 25

W & T Sensitive SURVEYING ALTIMETERS

READABLE TO ONE FOOT

SELF-BALANCING PRINCIPLE
No adjustment or setting required. No time lag.

ECONOMY
Time and money are saved because modern altimetry methods eliminate lines of sight. Small original investment is rapidly recovered.

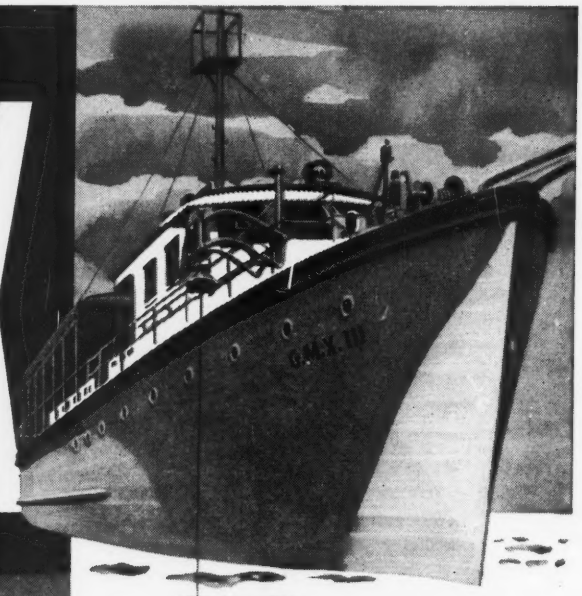
RANGES:
MINUS 1000 TO 3000 FEET
MINUS 1000 TO 6000 FEET
MINUS 1000 TO 15000 FEET

Write today for additional information

WALLACE & TIERNAN
PRECISION INSTRUMENTS AND ELECTRICAL MECHANISMS
Belleville 9, N. J.
In Canada: Wallace & Tiernan Products Ltd. • Box 54, Toronto 13

A-99

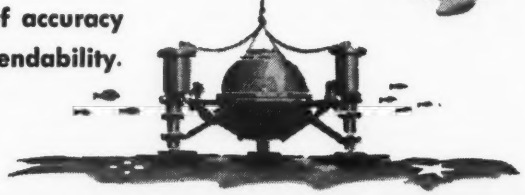
GMX



Detailed Analysis of Gravity and Aeromagnetic Surveys

Dependable
GRAVITY SURVEYS ON WATER AND LAND

Since 1925 GMX has been making and interpreting geophysical surveys throughout the world's petroleum regions. This long experience—combined with new techniques—is your assurance of accuracy and dependability.



GRAVITY METER EXPLORATION CO.

geophysicists

ESPERSON BLDG. HOUSTON, TEXAS

W. G. SAVILLE
A. C. PAGAN
L. L. NETTLETON
N. C. STEENLAND
M. W. BAYNES

VOLUME XIX JANUARY, 1954 NUMBER 1

GEOPHYSICS

A Journal of General and Applied Geophysics

REGIONALS, RESIDUALS, AND STRUCTURES*

L. L. NETTLETON†

ABSTRACT

A critical review of the various methods for determining regional effects indicates that neither the graphical systems nor the various numerical and mathematical systems provide a philosophically sound basis for separating a potential field into regional and residual components. The former depend on the judgment of the operator and the latter on assumptions or empirical steps in the mathematical derivation of the numerical factors or coefficients used in the calculations. Each system has its advantages and disadvantages and a proper appreciation of these is necessary for the successful application of either or both systems to a given problem.

The various published mathematical systems are compared by reducing their numerical factors to a common basis and listing them in tabular form. This comparison shows the gross variation in numerical coefficients and weighting factors derived by different mathematical approaches. Comparisons of the graphical system and certain of the grid systems, made by carrying them out over a gravity map of the same area, show the effect of these variations on second derivative maps. Other examples of applications are listed from maps in the geophysical literature.

It is concluded that the lack of an objective criterion for the isolation of anomalies is due to the inherent ambiguity in the sources of potential fields, but that in spite of the empirical nature of any regional method, the proper application of a system appropriate to the particular problem encountered can give very useful results.

INTRODUCTION

Regional effects in gravity and magnetic surveys have been a problem since the earliest days of prospecting with the torsion balance and the vertical magnetometer. It was recognized then that the measured fields contain effects that are not related to the possible geological irregularities or structures which the surveys were expected to find. Numerous schemes have been used for treating regional effects and a certain aura of mystery and conflicting claims have come to surround these treatments. Therefore, it seems worthwhile to review the fundamental principles on which the various systems now in use are based and to evaluate their possibilities and limitations.

THE AMBIGUITY OF POTENTIAL FIELDS

The problem of regionals and residuals arises in all geophysical methods which

* Revised and extended from a paper with the same title presented at the Annual Meeting of the Society of Exploration Geophysicists, St. Louis, Missouri, April 25, 1951. Manuscript received by the Editor September 15, 1953.

† Gravity Meter Exploration Co., Houston, Texas.

are based on measurement of a "potential"[1] field. Basically, the question is that of separating a potential field into possible component parts and of ascribing separate geologic causes to these parts. The problem is incapable of an exact solution because of the inherent ambiguity in defining the source of a potential field—a fact which has been pointed out many times in the geophysical literature (Skeels, 1947; Vajk, 1951; Nettleton, 1940, pp. 101–102, 205–206, 376–377). The ambiguity arises from the mathematical fact that, given the distribution of a gravity, magnetic or electric potential function over a surface (the surface of the ground or the flight level of an airborne survey), it is not possible to derive a single unique distribution of mass, magnetization, or electric charges which will account for that field.

The ambiguity is not dependent on the spacing or precision of the observations on the given surface. There are certain limits which can be placed on the nature and boundaries of the disturbing bodies but within these limits an infinite variety of solutions is possible. As the observations become more widely spaced or less precise, the range of possible solutions becomes greater. However, no degree of precision or amount of data will remove the fundamental uncertainties.

The fundamental ambiguity in the regional problem does not appear to be very well appreciated even at this late date. This is shown by the variety of schemes for removing regional effects which have been derived by different people at different times, and particularly by the prevalence of the idea that some particular scheme is superior because of its mathematical basis. The variety of regional treatments of gravity surveys, in particular, is probably the cause of the remark made facetiously by a geologist that "the regional is what you take out to make what's left look like the structure." In view of the uncertainties and ambiguities pointed out, this is perhaps about as good a definition of a correct regional as any that can be made. But this means that the determination of a satisfactory regional is a geological as well as a geophysical problem. If we can determine limits on the areal extent and relief of an anomaly which is a reasonable expression of the kind of structure we are looking for, we then have some idea of the type of regional to remove which will emphasize anomalies of this kind.

The earliest treatment of the regional was by means of smooth curves on profiles or smooth contours on maps. More recently, a class of methods has been developed which depends on numerical treatment of values at points in a regular array. In a recent review of Vajk's paper, Steenland (1952) has aptly termed the proponents of these two treatments as "smoothers" and "gridders." The aim of

[1] The word "potential," as used in this paper, is the mathematical term applicable to force fields in space, of which there are many. The potential function is a mathematical expression such that its derivative, or space rate of change in any direction, gives a force in that direction. The potential fields used in geophysical prospecting are the gravitational, magnetic, and electrical. The formulas for the force effects at a distance, from a heavy, magnetized, or charged body, may be derived from the corresponding potential expressions for that body.

much of the discussion which follows is to point out the advantages and limitations of these two classes of treatment.

GRAPHICAL METHODS OF ESTIMATING REGIONAL EFFECTS

The "smoothers" attempt to separate the measured field into two parts. The regional is the smooth part and is attributed to effects which are too deep or too broad or too great in relief to be possible expressions of structure or other disturbances of interest. The residual is the part of the picture left after subtraction of the regional. Obviously, the choice of the regional will dictate the nature of the residual map.

The choice of a regional is very largely empirical. In simple situations, such as a rather uniform gradient over a large area, the selection of a regional is not difficult and different operators will make about the same choice. As the regional background becomes complicated or the differences in magnitude of regional and residual effects become less, the choice becomes more difficult and arbitrary so that different people may arrive at different solutions.

There are three degrees of refinement which are commonly used.

The simplest method is that of drawing smooth contours and subtracting this set of contours from those of the observed map to contour the residual features. In situations where there are relatively sharp residual features, and particularly where the trend of the residuals is quite different from that of the regional contours, this method can be quite effective. This method is very difficult to use when low relief residual features are nearly parallel with steep regional contours, or where local disturbances occur near axes, saddles, or closures in the regional field.

A more refined method is to plot profiles along lines, usually more or less perpendicular to the regional contours or to the direction of regional geologic trends, to draw smooth regional curves on these lines, and to use these smooth curves to determine the location of the regional contours. Alternatively, the departures from the smooth curves can be transferred directly to a map if the profiles are close enough together to permit correlating residual features from one profile to another.

A still more elaborate method is to plot profiles on a network of intersecting lines. The locations of the lines may be dictated by the locations of the observations, by the pattern of the map itself, or, if control is uniformly good, the lines may be in a regular array. The advantage of the network of lines is that the two values from the regional curves at each point of intersection must be reconciled by modifying and adjusting the curves before the regional can be contoured. While these adjustments are empirical and often rather arbitrary, they give a third dimension to the control of the regional contours which is particularly useful as the regional field becomes more complicated.

Once the regional is determined and contoured, it may be subtracted from the observed map either graphically or numerically. In the former method, new contours are drawn through the intersections of observed and regional contours

where differences are equal and, thus, are contours of the residual. In the second method, a value is interpolated from the regional contours at each station and is subtracted from the observed value; the residual map is then contoured from these difference values. The latter method makes the contouring of the residual independent of the contouring of the observed values and has some advantages when stations are irregularly or widely spaced. When control is close and the original contours are carefully drawn, the two methods will give substantially the same result and the method of subtracting contours is much faster.

Numerical Operations and Grid Calculations

The ambiguity and dependence on personal judgment of the "smoothers," together with the very considerable labor by experienced personnel which is

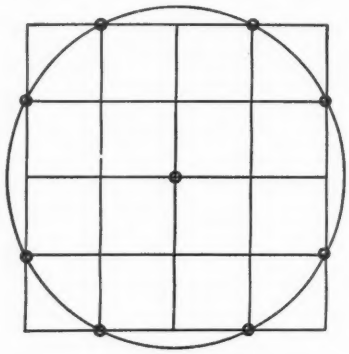


FIG. 1. Rectangular grid for one ring residual.

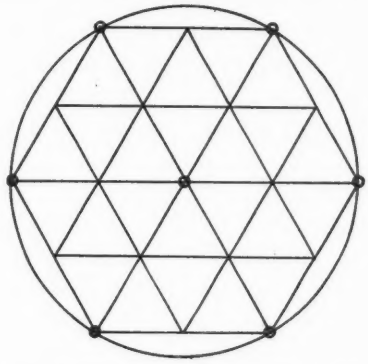


FIG. 2. Hexagonal grid for one ring residual.

required, have led to the development by the "gridders" of a variety of numerical operations which are intended automatically to isolate local anomalies by rapid routine calculation. Nearly all of these systems operate on a regularly spaced array or grid of values. The systems used by the "gridders" have been developed by two independent approaches, one largely empirical and the other analytical.

Empirical Grid Residual Systems

One of the simplest of the empirical systems is to use the average of observed values on a circle as the regional. The residual is the difference between this average and the observed value at the center of the circle. This can be reduced to a grid system if the values are interpolated at a regular array or grid of positions. In some cases, where stations are regularly spaced as at section corners, the observed values can be used directly, without contouring. A system using eight points on a square grid is shown in Figure 1. Another system using six points on a grid of lines at 60° is shown by Figure. 2.

In any center-point-and-one-ring residual method, the residual values and the nature of the residual map are directly dependent on the radius of the circle,

and to a more limited extent upon the number of points on the circle which are averaged. A discussion of the simple center-point-and-one-ring system with several examples which show the effect of variation of the radius of the circle on the nature of the resulting residual map has been given by Griffin (1949).

Analytical Calculation of Derivatives

The grid methods have been given a mathematical foundation by the application of potential theory to the calculation of derivatives of the potential functions (Evjen, 1936; Peters, 1949; Henderson & Zietz, 1949; Elkins, 1951; Rosenbach, 1953). The rather involved mathematical formulations have been reduced to practical schemes of calculation, using values from a regular grid of points to

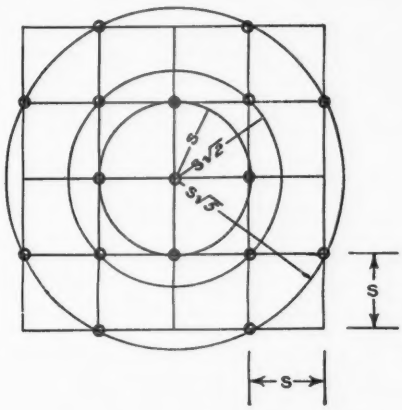


FIG. 3. Rectangular grid for three ring second derivative calculation.

determine averages around circles of different radii from a central point. These can be thought of as an elaboration of the simple one-ring method by which several rings are used instead of one, with the rings of different radii having different weights, some of which must be negative.

Figure 3 is an example of a grid of three rings used for second derivative calculations. Averages at distances of S, $S\sqrt{2}$, and $S\sqrt{5}$ are determined from four, four, and eight points, respectively.

All of these mathematical systems involve assumptions or empirical choices at certain stages in their reduction to practical use. These choices control the determination of the numerical coefficients by which the values read from a map are multiplied to determine the derivative values. The arbitrary nature of these final solutions has been pointed out, as is illustrated by the following quotations:

"From the foregoing it is evident that any number of coefficient sets may be developed. Their relative merits can be determined only by testing them." (Elkins, 1951, p. 39).

"These methods, being approximations, give results which depend to a considerable extent on the spacings used. . . . The results are more qualitative than quantitative in value but these methods have proven to be some of the better tools available for mass production analysis." (Peters, 1949, p. 304).

TABLE I

RESIDUAL AND DERIVATIVE FORMULAS

No.	Source	Formula
1	Center-Point-and-One-Ring	$\Delta G = G_0 - \overline{G}(s)$
1-a*	Center-Point-and-One-Ring	$\frac{\partial^2 G}{\partial Z^2} = \frac{4}{S^2}\left[G_0 - \overline{G}(s)\right]$
2	Henderson & Zietz, eq. (10)	$\frac{\partial^2(\Delta T)}{\partial Z^2} = 6.185\Delta T_0 - 8.374\Delta\overline{T}_1 + 2.189\Delta\overline{T}_2$
3	Henderson & Zietz eq. (13)	$\frac{\partial^2(\Delta T)}{\partial Z^2} = 2\left[3\Delta T_0 - 4\Delta\overline{T}_1 + \Delta\overline{T}_2\right]$
4	Henderson & Zietz, eq. (15)	$\frac{\partial^2(\Delta T)}{\partial Z^2} = 21\Delta T_0 - 32\Delta\overline{T}_1 + 12\Delta\overline{T}_2 - \Delta\overline{T}_3$

where, in Formulas 2, 3, and 4, $\Delta\overline{T}_0$, $\Delta\overline{T}_1$, $\Delta\overline{T}_2$, and $\Delta\overline{T}_3$ are average values at distances o, S, $\sqrt{2}S$, and $2S$ respectively.

5	Elkins, eq. (13)	$\frac{\partial^2 G}{\partial Z^2} = \frac{1}{60K^2r^2}\left[64\overline{H}(o) - 2H'(s) - 4H'(s\sqrt{2}) - 5H'(s\sqrt{5})\right]$
		$\frac{1}{60K^2r^2}\left[64\overline{H}(o) - 8\overline{H}(s) - 16\overline{H}(s\sqrt{2}) - 40H(s\sqrt{5})\right]$
6	Elkins, eq. (14)	$\frac{\partial^2 G}{\partial Z^2} = \frac{1}{28K^2r^2}\left[16H(o) + 2H'(s) - 3H'(s\sqrt{5})\right]$
		$= \frac{1}{28K^2r^2}\left[16H(o) + 8\overline{H}(s) - 24\overline{H}(s\sqrt{5})\right]$
7	Elkins, eq. (15)	$\frac{\partial^2 G}{\partial Z^2} = \frac{1}{62K^2r^2}\left[44H(o) + 4H'(s) - 3H'(s\sqrt{2}) - 6H'(s\sqrt{5})\right]$
		$\frac{1}{62K^2r^2}\left[44H(o) + 16\overline{H}(s) - 12\overline{H}(s\sqrt{2}) - 48\overline{H}(s\sqrt{5})\right]$
8	Peters, eq. (27)	$\frac{\partial^2 H}{\partial Z^2} = 1.156H(o) + 0.256\overline{H}(1) - 0.455\overline{H}(\sqrt{2}) - 1.359\,\overline{H}(\sqrt{5}) + 0.392\overline{H}(\sqrt{9.23})$
9	Rosenbach, eq. (16)	$\left(\frac{\partial^2 g}{\partial z^2}\right)_P = \frac{1}{24s^2}\left[96g_P - 18\sum g(s) - 8\sum g(s\sqrt{2}) + \sum g(s\sqrt{5})\right]$
		$= \frac{1}{24s^2}\left[96g_0 - 72\bar{g}(s) - 32\bar{g}(s\sqrt{2}) + 8\bar{g}(s\sqrt{5})\right]$

* It has been pointed out by Henderson and Zietz (personal communication) that, by application of eq. (12), p. 512, of their paper to the center-point-and-one-ring system, a derivative expression comparable to the other formulas can be written as

$$\frac{\partial^2 G}{Z\partial^2} = 4/S^2\{G_0 - G(s)\}.$$

TABLE II

EQUIVALENT FORMULAS WITH UNIT WEIGHT FOR CENTER POINT

Formula No.	Factor* K	$R=0$	Weighting Factors $r=s$	$r=s\sqrt{2}$	$r=2s$	$r=s\sqrt{5}$	$r=s\sqrt{9.23}$
1	1	1	−1				
1-a	4	1	−1				
2	6.185	1	−1.354	+.354			
3	6.000	1	−1.333	+.333			
4	7.00	1	−1.523	+.571	−0.48		
5	1.067	1	− .125	−.250		− .625	
6	0.571	1	+ .500	0		−1.500	
7	0.710	1	+ .364	−.273		−1.091	
8	1.156	1	+ .221	−.385		−1.175	+.339
9	3.000	1	− .750	−.333		+ .083	

* To calculate derivative values, we must include a factor $1/s^2$, where s is the grid spacing. For instance if r is the grid spacing on a map at scale $1k$, when $s=kr$. A common unit, for gravity, is gals/cm^2; with this unit, second derivative gravity values are usually of the order 10^{-15}. Other units used are mg/cm^2, mg/mile^2, gamma/mile^2. It would be very desirable to have these units standardized.

Comparison of Different Derivative Systems

The significance of the assumptions and qualifications in the development of the derivative formulas does not seem to be appreciated as much as it should be. The following paragraphs and tables point out the similarities and differences of various published systems in some detail by reducing the several formulas to similar and comparable terms.

All the second derivative calculation systems can be considered as of the form:

$$D = (C/S)^2(W_0H_0 + W_1\overline{H}_1 + W_2\overline{H}_2 + \cdots)$$

where D is the derivative value; H_0 the center point value; $\overline{H}_1, \overline{H}_2, \cdots$ are average values at rings 1, 2, $\cdots$; $W_0, W_1, W_2, \cdots$ are weighting factors; C is a numerical coefficient; and S is the distance represented by the unit grid spacing. Thus, the derived value is the product of a coefficient, C/S^2, multiplied into the weighted average value at the center point and at one or more circles at different radii from the center point. A condition common to all systems is that the sum of the weights must be zero. For all second derivative systems, the numerical coefficient includes the factor $1/S^2$; this condition ordinarily is not included in the "grid residual" systems which calculate simple differences, as in the usual application of the center-point-and-one-ring system.

The omission of the $1/S^2$ factor gives a grid residual map in entirely different units from those of a second derivative map although, as will be pointed out later, they may look very much alike.

The several systems can be compared more readily if we make the weight of the center point unity by dividing through by the coefficient for that term and changing the factor C to K where $K=CW_0$.

We will now make such a comparison for several of the published residual

and derivative formulas. In Table I, the formulas are listed in their published form. Table II lists the equivalent K values and the weighting factors for circles of the different radii involved in each formula.

It will be noted that, for the same radii, the magnitudes and even the signs of the weighting factors vary (but the sums of the weights are always zero) and that the magnitudes of K have a range with ratios of more than 10 to 1. Ideally, all of these systems, except Formula 1, should give the same derivative value.

To compare the systems further, Table III shows, for each formula, the calculated derivative value for the same field. It has been pointed out in the various papers quoted that the calculated values are dependent, to a considerable extent,

TABLE III

COMPARISON OF DERIVATIVES CALCULATED WITH DIFFERENT GRID SPACINGS

Formula No.	Grid Spacing	Calculated Value	% of Theoretical Value
1	¼	.090	9
	½	.292	29
	1	.643	64
1-a	¼	5.56	93
	½	4.55	76
	1	2.59	43
2	¼	6.23	104
	½	5.80	97
	1	3.72	62
3	¼	6.34	106
	½	5.72	95
	1	3.54	59
4	¼	6.26	104
	½	6.04	101
	1	4.65	78
5	¼	4.52	75
	½	2.51	42
	1	0.92	15
6	¼	4.21	70
	½	2.06	34
	1	0.67	10
7	¼	4.35	72
	½	2.22	38
	1	0.71	12
8	¼	5.09	85
	½	3.02	50
	1	0.96	16
9	¼	5.34	89
	½	2.51	42
	1	1.34	22

on the grid spacing chosen. To illustrate this factor, calculations have been made for three different grid spacings.

For simplicity, the field chosen is the gravity effect of a sphere and the point calculated is over its center. We will consider that the gravity effect at this point is unity and that the center of the sphere is at unit depth. The theoretical second derivative value over the center of this sphere is six units (Elkins, 1951, p. 39). Calculations are made for grid spacings of 1/4, 1/2, and 1, in units of depth to the center of the sphere, which means that the K values (except for Formula 1) are multiplied by 16, 4, and 1, respectively.

It should be pointed out emphatically that test calculations at a single point, as in Table III, are not a reliable criterion of the relative merits of different coefficient systems as will be shown later by application of certain of these formulas to a sample map. A set of coefficients that gives good results on an ideal theoretical field may give poor results on practical field data. The reverse also may be true. The final choice of coefficients rests on extensive comparative tests on field data of various degrees of precision, spacing, and complexity of disturbances.

A practical grid system must operate on a limited number of discrete points. The selection of these points, the manner in which they enter the calculation (i.e., their relative weights), and, particularly, the grid spacing itself have strong influences on the calculated results. Therefore, the resulting derivative map is only an approximation of a true mathematical representation and *its pattern is determined by the grid spacing, the number of rings used, and their relative weights, all of which, to a large degree, are empirically chosen.*

Stated in more mathematical terms, the analytical background of the derivative formulas depends on well defined properties of potential functions. In the application to grid calculations the continuous functions must be replaced by finite differences and the "derivatives" calculated may be quite variable depending on the choice of spacing and pattern of the points which determines these differences. Furthermore, the geophysical fields are too complex to be represented accurately by the analytical expressions from which the derivative formulas are determined. Therefore the validity of the result depends on the type of function being approximated, the region covered by the approximation, and the spacing and pattern of grid points used.

Comparison of Grid Residual and Derivative Systems

It has been mentioned that the units of the empirical grid residual system are different from those of the analytical derivative systems. The former gives simple differences in the same units as those of the original or observed field. The second derivative formulas all have a term involving the square of a horizontal distance. It has been pointed out (Henderson and Zietz, 1949, p. 516) that when this difference is taken into account the numerical relations between the results calculated by the two types of systems can be determined. This means that with

equivalent grid spacings, maps made by either system can be made to look much the same by choice of contour interval. In particular, the zero contour will be quite similar.

As an example, let us compare Formula 1 and Formula 7 in Table II. In the center-point-and-one-ring system (Formula 1), the weights of the center point and the ring are +1 and −1, respectively. In Formula 7 the center-point value is replaced by a value determined by the center-point and first ring, with weights of +1 and +.364; the outer ring is replaced by two rings, with weights of −.273 and −1.091, respectively. On a smooth map, the contributions of the first and second rings, with opposite signs, will approximately cancel and the result is determined very largely by the center point and outer ring. Then the derivative value is very nearly proportional to the residual calculated by the one-ring residual system, with a radius equal to that of ring 3, and the two types of calculation will contour into maps of similar appearance but in different units. If we calculate a derivative value from the center-point-and-one ring system (Formula 1-a) using the same radius as the outer ring of Formula 3, the two will give very similar results as is illustrated later (compare Figures 9 and 10 and Figures 11 and 12).

If the map is irregular, the multi-ring system has a definite advantage in that it is less affected by single values and tends to integrate the result into a smoother picture.

Filter Effect of Grid Calculations

The grid residual and derivative systems both have the objective of selecting or emphazing anomalies which may indicate structure, and of excluding: (1) those components which are too broad or too deep, or too large in relief to be reasonable indications of structure; and (2) those components which are superficial. The latter can be improved by analytical smoothing (which always increases the number of points which must be taken into account). This aspect of the problem has been elaborately treated by Grant (1952).

The desired selectivity of a grid or derivative calculation can be compared to that of an electric filter which will pass components of certain frequencies and exclude others. The ideal residual or derivative system would be one which would "pass" (i.e. emphasize) those components of a potential field which indicate structure and attenuate (i.e. reduce or remove) all others, both of larger and smaller magnitude. Well chosen grid calculations have very useful "filtering" characteristics but the "cut-off" is never sharp. In cases where the relative magnitudes of residual and regional components are widely different, the grid calculation "filter" will discriminate quite definitely and automatically between desirable and undesirable features. As the magnitude, particularly the horizontal dimensions, of the regional and residual features become more nearly alike the discrimination becomes less definite on the "low frequency" side and the "regional" features begin to appear more prominently on the derivative or grid calculation maps. On the other hand, if we are looking for small anomalies in the presence of

shallow or sharp disturbances, the smoothing may greatly reduce the desired features and the discrimination fails on the "high frequency" side.

Grid Calculations and Curvature

The operation of any grid system is rather closely analogous to determining the curvature of the potential field or "surface." This may be illustrated approximately by the geometry of a circle. The height, h, between the arc of a circle and a chord with a length $2S$, when h is small compared with the radius, R, is $h=S^2/2R$ or the curvature $=1/R=2h/S^2$.

If we think of this as an approximate analogy with the center-point-and-one-ring residual method, the height, h, corresponds with the residual value and the

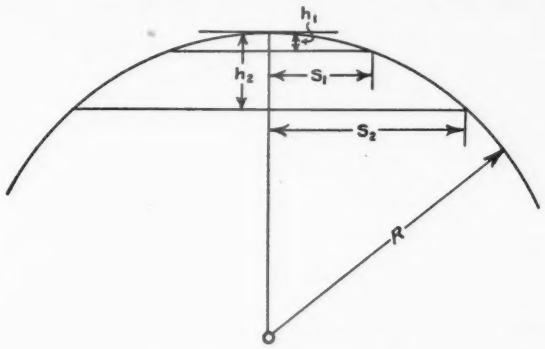


FIG. 4. Definition of curvature.

distance, S, with the radius of the ring. If we would divide the residual values by S^2, as in the second derivative calculation (i.e., by the square of the radius of the ring) we would have values approximately inversely proportional to the radius of curvature of the potential "surface" or directly proportional to its curvature. Since the residual values are taken as simple differences (i.e., corresponding to values of h) it is evident that these differences will be approximately proportional to the square of the radius of the ring used. Thus, in Figure 4, if S_2 is twice as great as S_1, h_2 will be four times as great as h_1. This approximation will apply in cases where the distance spanned by the diameter of the ring (i.e., $2S$ in Figure 5) is relatively small compared to the total width of the feature, either local or regional, over which the "residual" is being determined. This relation can be illustrated from Griffin's Figure 5 (1949, p. 45) which shows the variation in grid residual values at the center of a minimum with variation in the radius of the circle averaged. If we take the curve of ΔG vs. radius (over the Pierce Junction dome) and divide the ΔG values by the square of the radius, we get a nearly constant ratio, out to a radius of about 2.5 miles.

The same general considerations apply to the more complicated grid systems used for derivative calculations. In such cases, the span, or the area "bridged" by the calculation, may be considered as approximately the diameter of the outer

ring or the one with heaviest weighting. This is particularly true in a system such as that represented by Figure 3 and Formula 7, where the effects of the two intermediate rings tend to cancel each other on a smooth map. When second derivative values are calculated the amplitude coefficient is inversely proportional to the square of the "span," so the calculated value (which is roughly analogous to the reciprocal of the radius of curvature) ideally should not depend on the grid spacing used. However, practical grid calculations depend on selecting a relatively small number of points to represent the field over an area. This makes the calculated values and the general appearance of a derivative map strongly dependent on the grid spacing because of the varying degree with which the details within the pattern used for the calculation are picked up and entered into the calculation. For example in a situation such as indicated by Figure 5 a close grid, or one

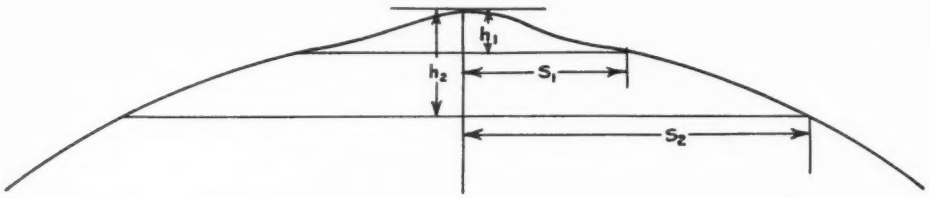


FIG. 5. Relation of measured curvature to local details.

with heavy weighting at the closest distances, will emphasize sharp details and will tend to give a relatively large "curvature" representative of a "bump" as determined by h_1 and the short "span" S_1 on an otherwise smooth arc. On the other hand a wide grid will give a much smaller "curvature," approximating that of the smooth arc itself, as represented by h_2, resulting from the wider span S_2.

The preceding paragraph is another expression of the "filter" effect previously mentioned. By choice of grid spacing we can emphasize either the smaller "bump" or the larger feature. The variation of calculated values in Table III and the examples, Figs. 8 to 13, also show the variation in the degree to which details of the "curvature" of the field are measured by grids of various spacing and relative weighting. These relations are important in considering the manner in which errors of measurement may be emphasized or suppressed.

Comparison of Graphical Regional and Grid Calculation Systems

Any grid calculation, once set up, is entirely automatic. This is both an advantage and a disadvantage. It is an advantage in that the system, being automatic, is not subject to the judgment of an operator. It is a disadvantage in that it is not easily adaptable to changing situations. Thus, a grid calculation may include a substantial contribution from a regional feature, while the flexibility of a graphical regional would permit the same feature to be quite completely excluded, if in the judgment of a "smoother" it should be excluded.

A comparison of the two systems is illustrated by Figure 6. The heavy dotted line shows a hypothetical "observed" gravity profile with two local anomalies. One of these is in a flat area, the other in an area of steep gravity change.

The nature of the "grid residual" calculation is indicated by the "bridging" effect of a calculation covering an area with a diameter corresponding to the straight lines or chords drawn between certain selected points on the "observed" curve. The heavy arrows indicate the differences between the average around the periphery of the area and the center point and correspond with the result from a center-point-and-one-ring "grid residual" system; the arrows point upward when the difference is positive and downward when the difference is negative. The Grid Residual curve below shows the result when these differences are

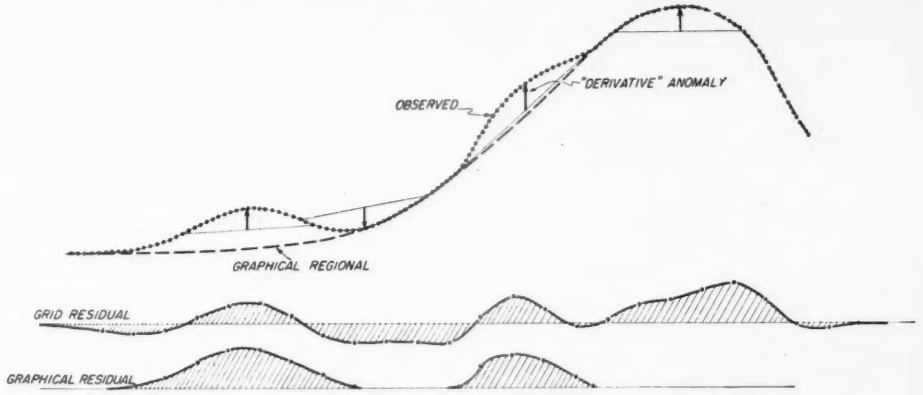


FIG. 6. Profile of hypothetical gravity curve with graphical and grid residual anomalies.

plotted for the entire length of the "observed" curve. Any more elaborate system, such as a second derivative calculation, has a qualitatively similar effect.

The heavy dashed line shows a graphical regional which might be drawn in this same situation. The Graphical Residual curve below shows the differences from this regional.

The principal differences between the "anomalies" as determined by the two systems are as follows:

(1) Both systems show the two local anomalies and their centers are at the same points.

(2) The two local anomalies are both shown as simple maxima by the Graphical Residual and as narrower maxima with flanking minima by the Grid Residual system.

(3) The positive amplitude is considerably greater for the Graphical Residual. For the Grid Residual curve, the total amplitude from the bottom of the flanking minima to the top of the maximum is approximately the same as the positive amplitude of the graphical residual. This relation depends on the choice of a radius appropriate to the size of the anomalies.

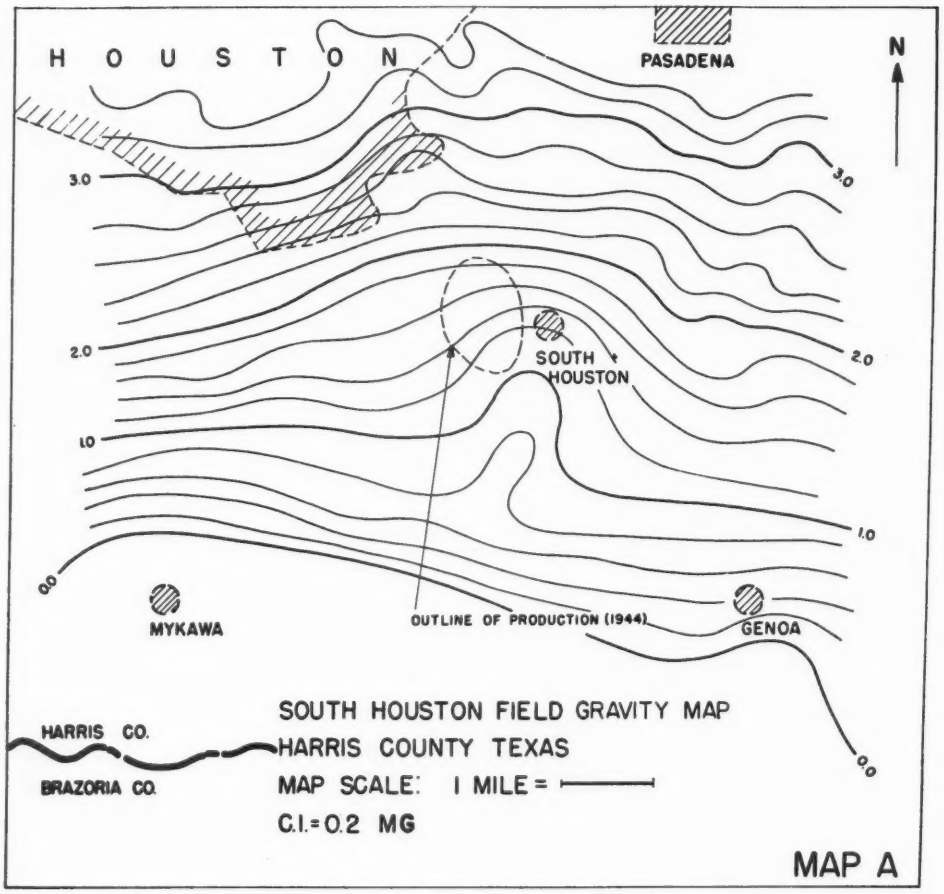


FIG. 7. Map A: Observed gravity, South Houston area. (Courtesy Robert H. Ray Co.)

(4) It is evident that any calculations of mass anomalies to fit a local gravity (or magnetic) anomaly would be directly applicable to the Graphical Residual (provided a proper choice of regional were made) but would not be applicable to the Grid Residual calculation.

(5) The Grid Residual system is very effective in indicating the location of local anomalies, even when the regional is very steep (and where the choice of a graphical regional might be quite difficult).

(6) The Grid Residual system shows a comparatively large positive anomaly over the apex of the regional maximum, whereas, with graphical smoothing, this feature is included entirely in the "regional" and no anomaly is shown. This illustrates the manner in which a choice can be made in constructing a graphical regional which will include or exclude a feature more or less completely; such a choice can never be made automatically by any grid-type calculation.

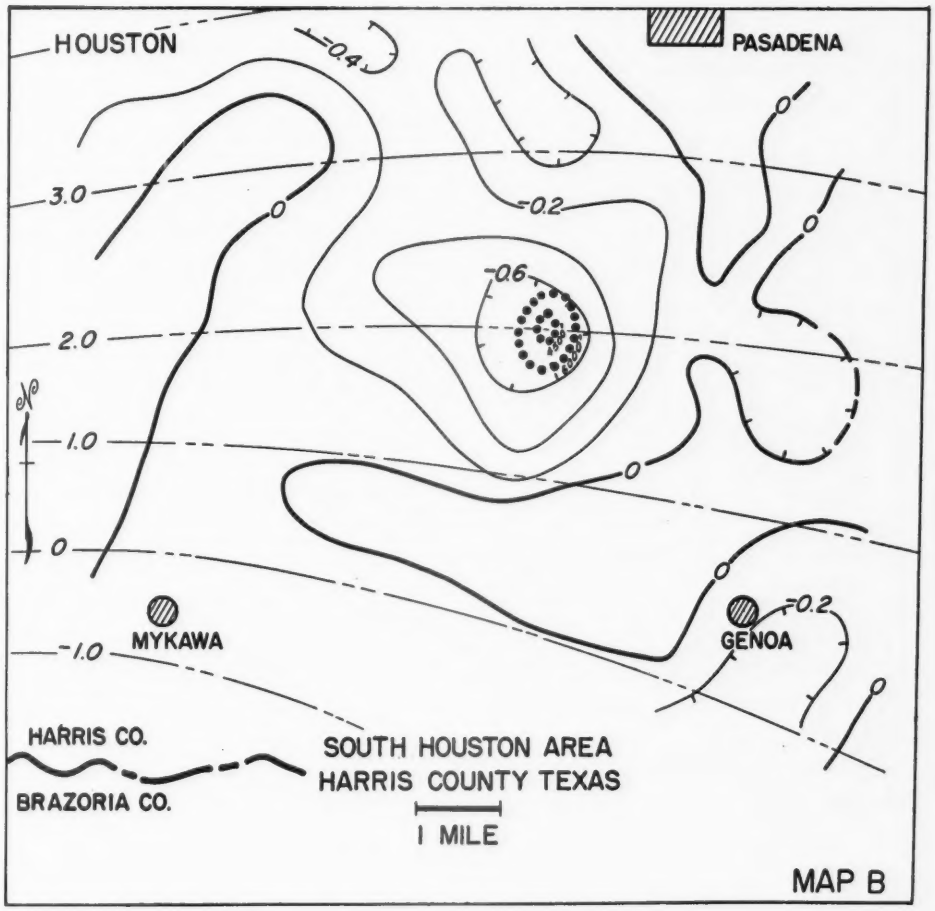


FIG. 8. Map B: Graphical residual, South Houston area.

A Comparative Application of Different Systems

To illustrate and compare the results of the various residual systems, we have carried out several different calculations over the same area. The area chosen is that around the South Houston salt dome, using the map from Griffin's paper (1949) because: (1) it is a fairly typical example of a local anomaly in an area of strong regional effects, and (2) it has been the subject of other studies[2] of residual effects which can be compared with those of this paper. The 4,500 ft and 6,000 ft contours on the salt, shown by small dotted circles, are taken from Eby's paper (1945 or 1948) on this dome.

[2] See, for example, the paper in this issue of GEOPHYSICS by Fraser Grant (pp. 23–45).—*The Editor.*

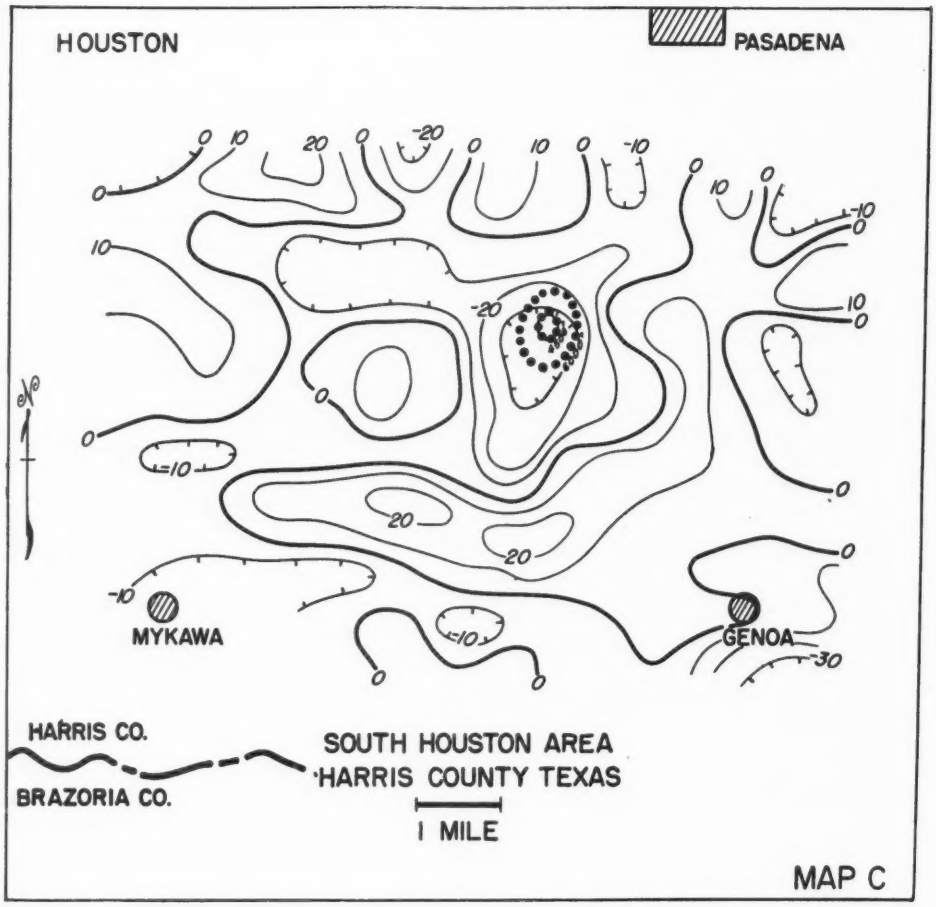


FIG. 9. Map C: Second derivative map, South Houston area, calculated from Formula 7 with one-half mile grid spacing; contour interval 10×10^{-15} c.g.s. units.

The test of different systems is shown by the following maps over the South Houston area:

Map A (*Figure 7*) is the observed gravity map, with contour interval 0.25 mg, taken directly from Griffin's paper.

Map B (*Figure 8*) is a residual map from a graphical regional, determined from a net of profiles; the regional is shown by the smooth, dashed background contours at 1.0 mg interval.

Over the same area, a rectangular grid was laid out at $\frac{1}{2}$ mile spacing and gravity values were written in, to 0.1 mg, from the contours, at each grid corner. From this grid of gravity values, two sets of second derivative values were calculated (all in 10^{-15} c.g.s. units; i.e. 10^{-15} gal/cm^2) as follows:

Set 1 used the $\frac{1}{2}$ mile unit grid spacing ($S = \frac{1}{2}$ mile) and a $\frac{1}{2}$ mile calculation interval.

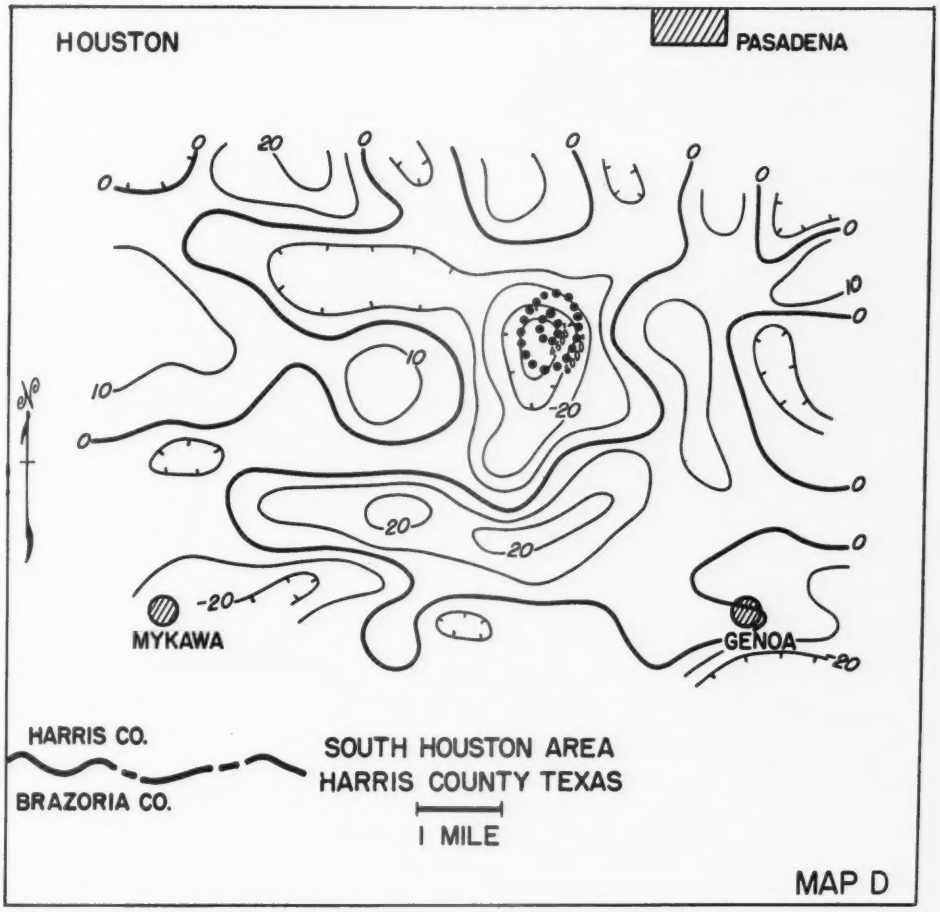


FIG. 10. Map D: Second derivative map, South Houston area, calculated from Formula 1-a with one-half mile grid spacing (radius=$\frac{1}{2}$ mile$\times\sqrt{5}$).

Map C (*Figure 9*) is calculated from Formula 7.

Map D (*Figure 10*) is calculated from Formula 1-a with $S=\frac{1}{2}$ mile$\times\sqrt{5}$, to make the one ring have the same radius as the outer ring of Formula 7.

Set 2 used a 1 mile unit grid spacing ($S=1$ mile) and a $\frac{1}{2}$ mile calculation interval.

Map E (*Figure 11*) is calculated from Formula 7.

Map F (*Figure 12*) is calculated from Formula 1-a with $S=1$ mile$\times\sqrt{5}$.

Map G (*Figure 13*) is calculated from Formula 3.

Certain likenesses and differences between the results of the various systems are apparent from comparison of these maps.

(1) The graphical residual and all of the derivative maps show a minimum centered quite well over the salt dome and from the standpoint of finding an anomaly by which the dome could be located, any of them would serve.

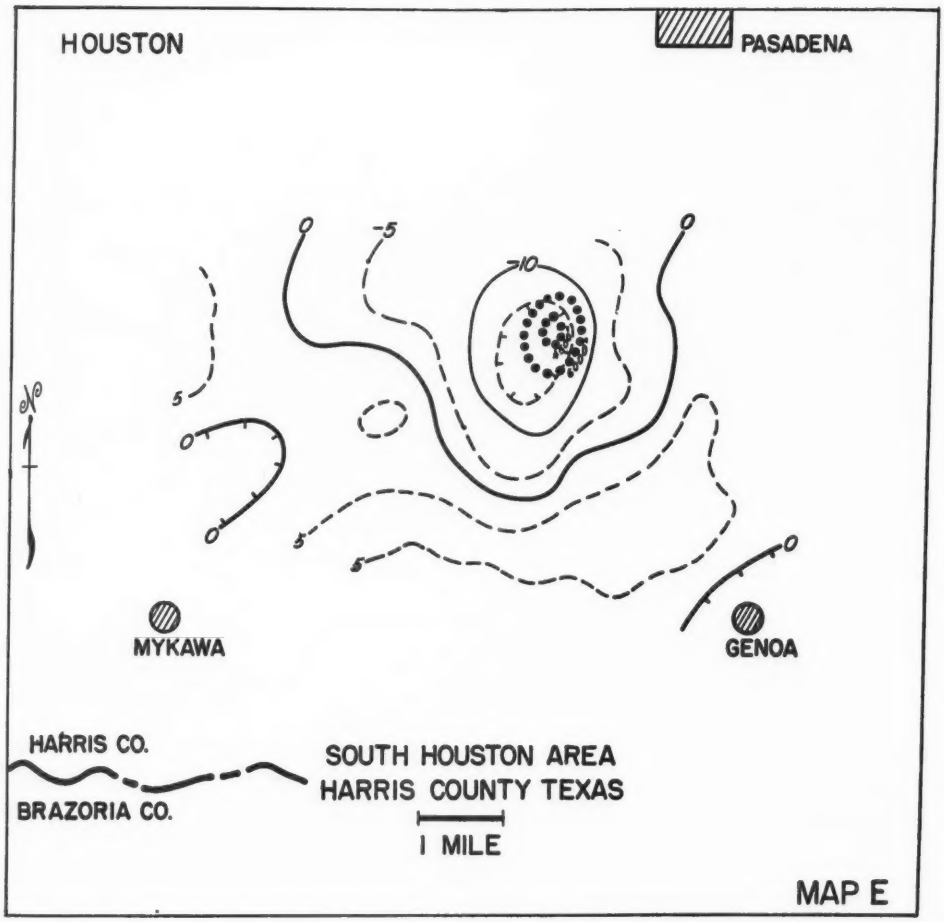


FIG. 11. Map E: Second derivative map, South Houston area, calculated from Formula 7, with one mile grid spacing; contour interval 10×10^{-15} c.g.s. units (dashed contours at 5 unit interval).

(2) The gravity relief of the minimum shown by the graphical residual, Map B, is about 0.7 mg. This anomaly is of reasonable magnitude and lateral extent if the salt column is assumed to be vertical below the 6,000 ft contour, where it has a diameter of about 4,000 ft. This is the only map which can be used to compare with directly calculated gravity effects since it gives values and contours in the usual gravity units (milligals) while the derivative maps are in dimensionally different units, being divided by the square of a distance.

(3) The calculated second derivative values are quite different for the different spacings, although with ideal and infinitely precise data they should be substantially the same (as shown by the calculated values of Table III). This is because errors and irregularities in the original values are relatively more magnified in the smaller spacing calculations, which depend on smaller differences and

large coefficients (the coefficients are four times greater for the $\frac{1}{2}$ mile spacing than for the 1 mile spacing) and is another example of the emphasis of small features illustrated in Figure 5. For example, the amplitude of the central anomaly calculated by Formula 7 with $\frac{1}{2}$ mile spacing is nearly double that calculated by the same formula with 1 mile spacing.

(4) The maps calculated from Formula 7 with three rings are very similar to those calculated with Formula 1-a, with one ring having the same radius as the outer ring of Formula 7. This is because in Formula 7 the first and second rings have coefficients of opposite sign, which tend to cancel each other so that the principal contribution comes from the outer ring.

(5) The calculation with Formula 3, with one mile spacing, is more irregular

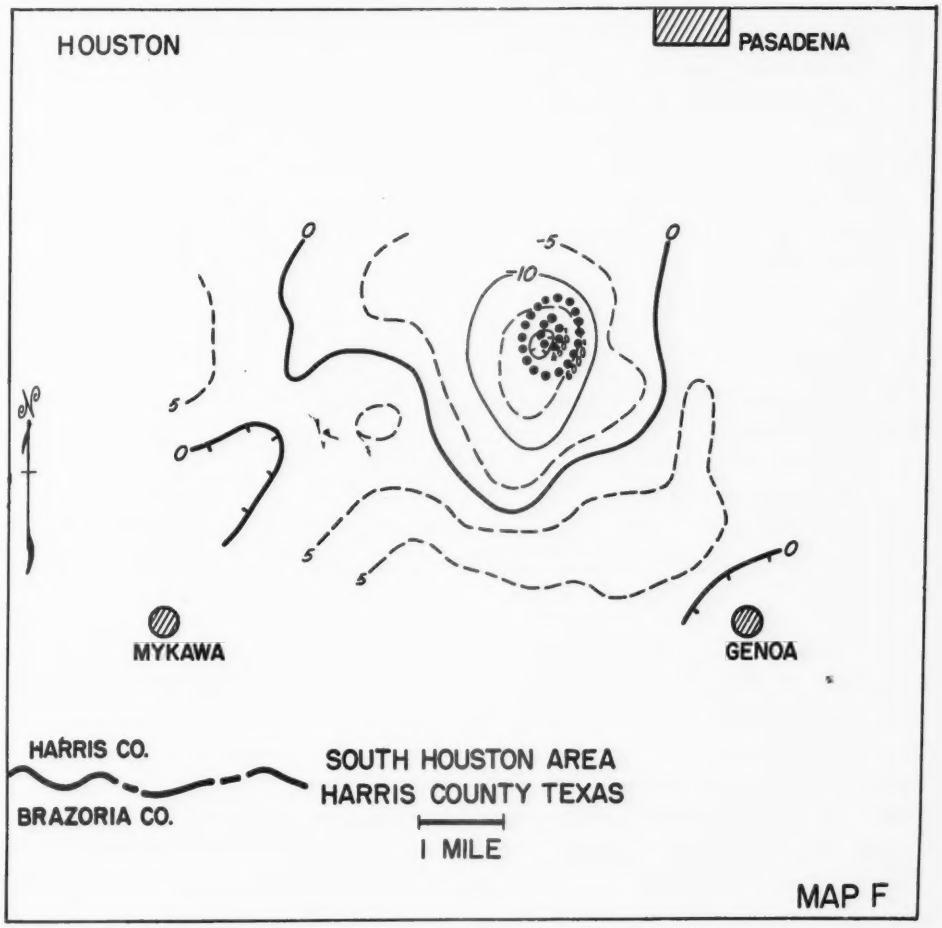


FIG. 12. Map F: Second derivative map, South Houston area, calculated from Formula 1-a with one mile grid spacing (radius = 1 mile $\times\sqrt{5}$); contour interval 10×10^{-15} c.g.s. units (dashed contours at 5 unit interval).

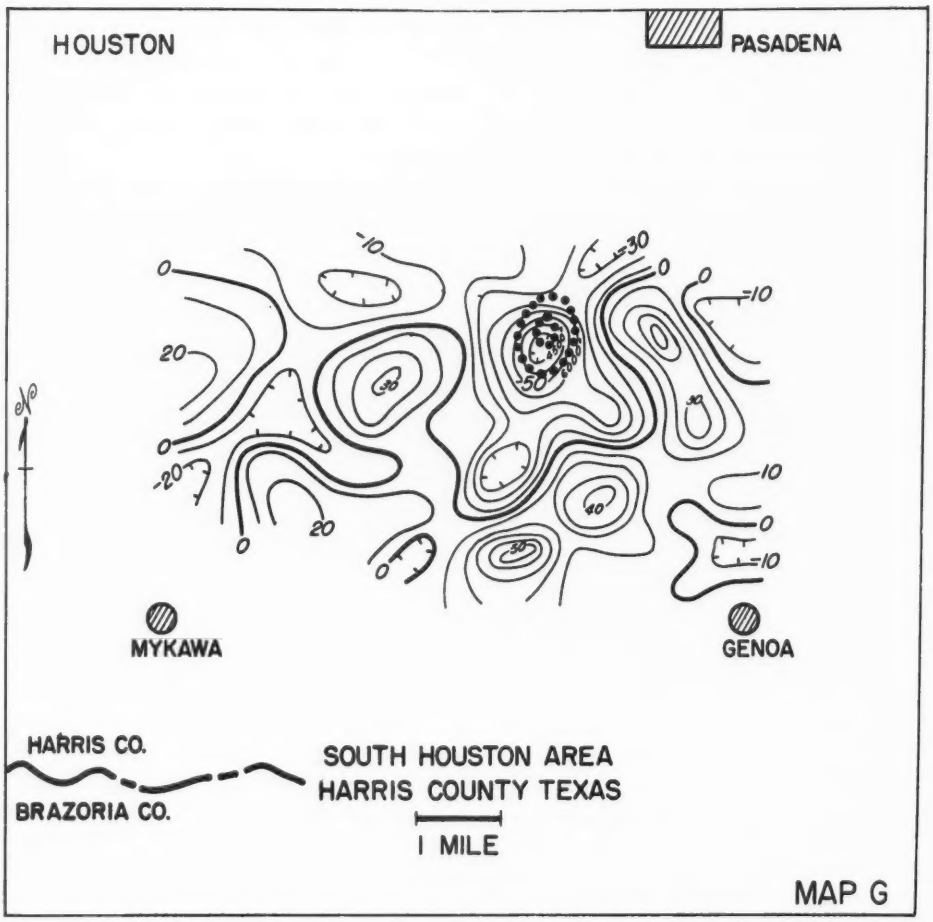


FIG. 13. Map G: Second derivative map, South Houston area, calculated from Formula 3 with one mile spacing; contour interval 10×10^{-15} c.g.s. units.

and gives higher values than the calculations with $\frac{1}{2}$ mile spacing with the other formulas used. This is because of the high value of the coefficient for the first ring which has the effect of making the differences from the center point to the first, or inner, ring dominate the result rather than those to the outer ring as in Formulas 7 and 1-a. The values from a $\frac{1}{2}$ mile calculation with Formula 3 were so large and erratic that they could not be contoured into a reasonable map.

(6) The differences between the second derivative maps calculated with different formulas illustrate the influence of the chosen factors in the several mathematical derivatives. These factors make much more difference in the practical results than do the mathematical details. In fact, the simplest system of all, i.e., Formula 1-a based on the center point and one ring, gives a result which is about as good as any. All of this is an example of Elkins' (1951, p. 39) statement

which will bear reiteration by quoting the entire paragraph:

"From the foregoing, it is evident that any number of coefficient sets may be developed. Their relative merits can be determined only by testing them. There should be two kinds of tests. The first should be a test on mathematically accurate data for simple anomalies for which a check against the theoretically correct second derivative values is possible [as has been carried out in Table III]. From this can be found whether or not the approximations involved in the derivation of the formula and the use of a grid cause too great inaccuracy. The second should be a test on actual gravity data to find if the errors in practical data cause too much disturbance."

Other Examples

The geophysical literature contains numerous examples of the application of both graphical and grid calculations to resolve local anomalies. These can be found in the papers by Peters, Hammer (1950), Elkins, Henderson and Zietz, Cortes (1953), and Griffin. A few comments on some of these may help to further illustrate the points brought out in this paper.

Hammer's Figures 6 and 7 give a very good example of the development of residual anomalies by subtraction of a smooth, graphical regional.

Elkins' Figures 15 and 16 provide a good example of the efficacy of the second derivative in developing elongated local anomalies with trends nearly parallel with that of steep regional contours. This is a situation difficult to handle by graphical methods. His Figures 17 and 18 illustrate a case where the strike of the anomaly is at a large angle with the regional and where the disturbance is evident by a local bowing of the observed contours. This case could be handled reasonably well by graphical methods. His Figures 12 and 14 show the manner in which overlapping local anomalies, in an area of regional reversal, can be resolved by a derivative calculation; this case is difficult to handle by graphical methods.

Peters' Figures 12 and 13 give another example of the resolution of overlaplaping disturbances by a derivative calculation, and Figure 14 shows how this resolution is further sharpened by using a higher derivative.

Henderson & Zietz' Figures 3 and 4 give another example of the very strong effect of the grid spacing on the calculated values and on the character of the resulting map. Note that Figure 3 calculated with the smaller grid spacing is much sharper and shows much greater irregularity, even though it is contoured with twice the interval of the smoother map (Figure 4), calculated with the wider grid spacing.

Cortes' (1953) Figures 2a and 2b provide an example of the comparison of grid residual and derivative treatments. The results of the two calculations are very similar in appearance (but in different units) and both develop a clear anomaly (over an area of scattered production), which is difficult to recognize on the observed map because the anomaly is parallel with the contours where the regional gradient is very steep.

Griffin's maps give a different type of illustration of the effect of grid spacing, since they are all in simple gravity differences for a center-point-and-one-ring calculation. Their values could be multiplied by $4/S^2$ to give second derivative

values comparable from one map to another, but the increasing emphasis on small features and errors as the grid spacing decreases would appear in much the same way.

CONCLUSIONS

The review of various methods of treating the regional effects and of isolating local anomalies shows that there is no single or direct answer to the problem. The fundamental difficulty is in the ambiguity in the source of a potential field and the lack of a clear criterion for separating it into component parts. The mathematical background of the several systems of derivative calculations, used by the "gridder," does not provide the desired criterion because, at certain steps, assumptions or empirical choices have to be made and variations in them produce gross variations in the final result when applied to practical data with the usual irregularities from small errors of measurement and from local disturbances. On the other hand, the use of empirical and graphical methods of separating the field into its components, as used by the "smoother," is subject to the judgment of the operator. Both methods have very great usefulness and one or the other or a combination of both is vital in the interpretation of potential field measurements. When carefully used and with a proper appreciation of their limitations they provide results which are much less ambiguous than might be expected and which can serve to isolate the geologically significant components of the field measurements.

REFERENCES

Cortes, Henry C., 1953, Geophysical progress: Geophysics, v. 18, no. 3, p. 510–524.

Eby, J. Brian, 1945, Geophysical history of South Houston salt dome, Harris Co., Texas: Bull. A.A.P.G., v. 29, no. 2, p. 210–214. Also 1948, Geophysical case histories: v. 1, p. 43–47.

Elkins, T. A., 1951, The second derivative method of gravity interpretation: Geophysics, v. 16, p. 29–50.

Evjen, H. M., 1937, The place of the vertical gradient in gravity interpretation: Geophysics, v. 1, no. 1, p. 127–136.

Grant, Fraser S., 1952, Three dimensional interpretation of gravity anomalies, Part II: Geophysics, v. 17, no. 4, p. 756–789.

Griffin, W. Raymond, 1949, Residual gravity in theory and practice: Geophysics, v. 14, no. 1, p. 39–56.

Hammer, Sigmund, 1950, Recent developments in gravity prospecting: Colo. School of Mines Quarterly, v. 45, no. 4A, p. 87–103.

Henderson, Roland A. and Zietz, Isadore, 1949, Computation of second vertical derivatives of geomagnetic fields: Geophysics, v. 14, no. 4, p. 517–534.

Nettleton, L. L., 1940, Geophysical prospecting for oil: New York, McGraw-Hill Book Co., Inc.

Peters, L. J., 1949, The direct approach to magnetic interpretation and its practical application: Geophysics, v. 14, no. 3, p. 290–320.

Rosenbach, Otto, 1953, A contribution to the computation of the "second derivative" from gravity data: Geophysics, v. 18, no. 4, p. 894–912.

Skeels, D. C., 1947, Ambiguity in gravity interpretation: Geophysics, v. 12, no. 1, pp. 43–56.

Steenland, Nelson C., 1952, Review of Vajk paper listed below: Geophysics, v. 17, no. 2, p. 409.

Vajk, Raoul, 1951, Regional corrections of gravity data: Geofisica Pura e Applicata, Milano, Italy, v. 19, fasc. 3–4, p. 129–143.

A THEORY FOR THE REGIONAL CORRECTION OF POTENTIAL FIELD DATA*

FRASER S. GRANT†

ABSTRACT

An analytical method based on the theory of statistical probability is developed for separating regional from local potential field effects. It is applied to an objective test on an artificial problem, as well as to a gravity survey that has already been the subject of studies of other averaging methods. It succeeds in both tests with good accuracy, and points up the danger of arbitrariness in the use of numerical methods.

INTRODUCTION

There is no longer any question that potential field measuring devices are sensitive enough to register faithfully the local effects of many types of geological structures and configurations; yet it is generally conceded that the effectiveness of these methods in prospecting is severely limited by indeterminacy in the interpretation of field data. A great deal of the blame for this has been laid upon the ambiguity that is inherent in the mathematical process of potential field interpretation (Skeels, 1947) but many geophysical workers privately admit that this is less of a restraint upon the use of direct interpretation procedures than the uncertainties that arise in the reduction of raw data to the residual form.

The chronic source of difficulty occurs in the process of separating locally anomalous fields from the regional background, since the large scale reductions for planetary effects seldom disturb the local picture. By the very undertaking of this operation, however, it is implied that one either knows beforehand what sort of effects one seeks to isolate from the regional map, or has a working criterion to distinguish between the effects of the regional geology and those of locally irregular conditions. The first of these implications does not always apply, and the second, unhappily, is not always infallible; but without the benefit of a rather detailed prior knowledge or prejudgment of the structure of a new area, such a working criterion is nevertheless an indispensable practical necessity and is usually fixed on the basis of areal extent. Thus a "regional anomaly" is defined, for practical purposes, as a field that is too broad to suggest the object of exploration; and it is generally assumed to be smooth and regular, suggesting characteristically the field due to a deep-seated disturbance. "Local anomalies" is the term given to the actual local irregularities in the regional field which might reflect the presence of the type of geological condition that is sought, whereas "residual anomalies" are by definition the residues that one obtains by subtracting an estimate of the regional anomaly from the regional map. The object of the regional correction, it need hardly be added, is to calculate the regional ef-

* Manuscript received by the Editor July 28, 1953.

† 9 Highland Ave., Toronto, Ontario, Canada.

fect by some sort of numerical analysis and to obtain thereby a map of the residual anomalies, which one strongly hopes bears more or less resemblance to the map of the local anomalies. Admittedly it sometimes happens that this criterion fails to describe the relationship between the phenomena that are sought after and those that are not, as, for example, when the looked-for structure produces a smooth, broad field comparable in extent with the regional anomaly. In such cases interpretation cannot be made on the basis of potential field data alone. But disregarding these rather pathological cases, it serves well enough for a wide variety of practical problems.

The regional correction is often a critical phase of the interpretation, and one of the most sensitive sources of error; it is therefore of the greatest practical importance that it be made as carefully and as accurately as possible. Many geophysicists feel that here lies one of the major obstacles to the fuller use of quantitative and direct interpretation; and indeed, it can hardly be denied that there is small value in a highly skilful interpretation of incorrect or unrepresentative data.

Very little has been published on how to determine the regional effect. In much of the earlier geophysical work, corrections were applied on the assumption that the regional gradient was constant, at least within limited regions. This system too often proved inadequate and misleading, and frequently it developed that when neighboring sections of a larger picture were juxtaposed, fictitious residual anomalies appeared at the lines of contact. A wide popularity was enjoyed for a time by the "graphical" method, in which the regional contours were drawn in by eye and residuals scaled off and contoured on another sheet; but this process was unsystematic and depended rather too much upon personal judgment; it now seems to have been almost entirely abandoned. The most widely used method today is, by all accounts, the so-called "averaging" method, in which the regional effect at a given point is taken to be the average of the values of the total field at a number of points distributed symmetrically (although otherwise rather arbitrarily) about the given point. Writers have been careful not to claim any real physical basis for this system, which they designate as purely an arbitrary numerical operation; thus the residual field is explicitly a function of the distribution of points used in the averaging process, a fact that has been clearly demonstrated by Griffin (1949) in several examples from gravity surveys. This is an obvious handicap to the interpreter, since it means that the results obtained by using one pattern are not strictly comparable with those obtained by using another. It is therefore impossible to know how much physical significance appertains to any. Thus, although the averaging method is more systematic than its predecessor, it is doubtful that it is more accurate; and although the personal factor disappears from the processing of the data, it returns much enhanced in the final interpretation.

Vajk (1951) concludes that, inasmuch as regional fields are subject to the same ambiguity of cause as are all other potential field phenomena, the regional effect

itself cannot be determined uniquely, nor can it be properly eliminated by mechanical procedures such as averaging or smoothing. He contends further that regional correction is essentially a problem in geological interpretation, and he argues in favor of the use of graphical methods in its solution. Vajk gives a well reasoned presentation of his case, but it must be admitted that his conclusion is a most repugnant idea to the geophysicist. It runs counter to one of the fundamental purposes of geophysical science, which is to eliminate personal judgments and prejudices as far as is practically possible through systematic application of the rules of exact logic. To do less is to undermine the potential value of geophysical exploration and to ignore its most conspicuous advantages.

THEORY

To determine the regional effect, an analytical device is needed that is able to smooth out the local disturbances. Let the field over the surface of the ground, which we assume provisionally to be a horizontal plane, be represented by the function $\gamma(x, y)$, upon which we place no restriction other than that it be everywhere bounded and analytic. The function γ is purely a theoretical description, since in practice it cannot be determined except by physical measurement at a number of isolated points and these measurements are inherently liable to error. Yet even if the measurements themselves were precise, they would usually be influenced by local disturbances emanating from near-surface inhomogeneities which affect a single observation and not its neighbors. These generally are randomly distributed in the field, and so have essentially the same result (although often in greater degree) as instrumental errors, and also about the same nuisance value, since they do not contribute any useful geological information. By warping contours, they tend to camouflage or obscure the useful features of the picture sought, so that in general one wishes to find a description of γ that is free of all such random and extraneous influences. To this end, local disturbances are grouped indiscriminately with errors due to all other causes into a term which we shall call the "intrinsic indeterminacy of observation," which may vary in degree from place to place, but always retains its random character. Although in practice the size of this term is usually decided by personal choice, a maximum useful estimate can be made in the specific case on the basis of certain tests.

This lack of determinacy among field observations poses rather a fundamental problem in the interpretation of geophysical data, and one which seldom has received the attention due it in the literature on that subject. We may deal with it by assuming that every measurement has some probability distribution, which implies that we recognize the *measured* field $g(x, y)$ (as distinguished from the theoretical field $\gamma(x, y)$) to be to some extent uncertain. Thus if measurement of g were repeated a large number of times at a given point, the values would not be identical but would fall into a normal frequency distribution (disregarding the possibility of systematic error, such as instrumental bias), whose

mode is the value of γ at that point. Then $\gamma(x, y)$ will be the expected value (Weatherburn, 1952, chapter 12) of the measured field $g(x, y)$ at every point (x, y), i.e.:

$$\gamma(x, y) = \frac{\beta}{\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} g(u, v)e^{-\beta[(x-u)+(y-v)^2]}dudv, \tag{1}$$

where the standard deviation is $1/\sqrt{2\beta}$, and is at least as large as that of any measurement.

In effect, the standard deviation must be chosen large enough to embrace the "intrinsic indeterminacy of observation," and this becomes a matter for the interpreter to decide. If the value chosen is large enough to include as well all local anomalies within the range of uncertainty of the data, then the function γ will describe a field in which these features are smoothed out, and in principle this is what we shall define to be the regional effect.

The subsequent work is considerably simplified if γ is calculated at the origin of the (x, y) coordinates. This involves no loss of generality, since the origin may be placed anywhere. Then, if the cartesian coordinates (u, v) are replaced with polar coordinates (ρ, ϕ),

$$\gamma(o) = \beta\pi^{-1}\int_0^{\infty}\int_0^{2\pi} g(\rho, \phi)e^{-\beta\rho^2}\cdot\rho d\phi d\rho$$

$$= \int_0^{\infty} g(\rho)\Lambda'(\rho)d\rho,$$

where $g(\rho) = 1/2\pi\int_0^{2\pi} g(\rho, \phi)d\phi$ and $\Lambda'(\rho) = 2\beta\rho e^{-\beta\rho^2}$. Λ may be expressed in non-dimensional form by writing ρ in units of s, the mesh side if the survey net is square, or an average station spacing if it is not. If β is then replaced with $\tau = \beta s^2$, the integral becomes

$$\gamma(o) = \int_0^{\infty} g(\rho_1)\Lambda'(\rho_1)d\rho_1 \tag{2}$$

where $\Lambda'(\rho_1) = 2s^{-1}\tau\rho_1 e^{-\tau\rho_1^2}$ and $\rho = \rho_1 s$.

Two Dimensions

In special cases where the regional effect appears to be essentially constant in the horizontal direction parallel to OY, or in other words "two-dimensional," the appropriate expression for its value at the origin of the x coordinates is

$$\gamma(o) = \int_{-\infty}^{\infty} g(\xi_1)\lambda'(\xi_1)d\xi_1 \tag{3}$$

where $\lambda'(\xi_1) = s^{-1}\tau^{1/2}\pi^{1/2}e^{-\tau\xi_1^2}$ and $\xi = \xi_1 s$.

The integrals (2) and (3) are most conveniently evaluated by breaking up

the domain into compartments or zones, in each of which g may be given some mean value; and a further simplification may be made by choosing the intervals of r_1 and x_1 to be such that $\int\Lambda'(\rho_1)d\rho_1$ and $\int\lambda'(u_1)du_1$ have simple fractional values in each zone. Then the integrations may be performed by summing up the contributions from the individual zones with the aid of templates or graticule charts. Suitable limits of r_1 and x_1 for the construction of templates are given in Table I. The values given are for $\tau=1$, but it is easy to verify that they may be converted to any other value of τ by dividing through the table by the square root of the new τ.

TABLE I

$\int_0^{r_1}\Lambda(\rho_1)d\rho_1$	r_1	$\int_0^{x_1}\lambda(u_1)du_1$	x_1
0.0	0.000	0.00	0.000
.1	.324	.05	.089
.2	.472	.10	.179
.3	.597	.15	.272
.4	.715	.20	.371
.5	.832	.25	.477
.6	.955	.30	.595
.7	1.097	.35	.733
.8	1.268	.40	.905
.9	1.518	.45	1.163
1.0	∞	.50	∞

Choosing the Proper Value for τ

In choosing the best value to use for τ, the ideal objective is to smooth out local anomalies without disturbing the regional background. In order to level out even small minor features, however, such large values are required for the standard deviation that only the very broadest regional fields would be unaffected by the smoothing; therefore the ideal objective is impractical except where the difference in extent between local and regional anomalies is relatively very great. Usually a certain amount of compromise will be inevitable; that is, the effect of applying the smoothing function will be to flatten out slightly the regional anomaly and to leave some residue from the local anomaly in the regional picture. The practical objective, therefore, is to endeavor to use that value of τ for which these two effects compensate each other exactly within the domain of the local anomaly.

To find τ from the contour map it is assumed that, within a small area, the regional anomaly is affected by the smoothing function in about the same degree percentagewise as some representative algebraic field, such as, for example the field due to a point source, or, if it is two-dimensional, as that due to a horizontal line. Also it may be assumed that the residue from the local anomaly after smoothing will be approximately equivalent to the residue which would be obtained from a point or line source at some depth. Expressions for γ appropriate to these two types of field are given, with their derivation, in an appendix.

There are several semi-empirical methods by the aid of which suitable values may be found for the depths to the point or line sources that give the best representations of the local and regional fields, and these probably may be used with about equal success. A better procedure on the whole is to choose a profile passing through the local disturbance in the direction of the maximum regional gradient, and to lay this over a chart on which several theoretical profiles are drawn and to find the most likely fit possible. It must be emphasized that this type of representation is merely a convenience and is in no sense an interpretation; no physical significance is attached to these depths and any combination of parameters which appears to give a satisfactory approximation must be equally admissible. Moreover, it is not at all necessary to use point or line source profiles, since any type of profile which may be described by an algebraic function may be used for the purpose in hand. In this way it should always be possible to find some sort of theoretical profile that provides a suitable estimate of the regional background within the domain of the local anomaly. Lest it should be inferred that this is a disguised use of the graphical principle, it is worth repeating emphatically that it is not assumed that the theoretical model *is* the regional field, but only that the percentagewise effect produced by smoothing is about the same in the two cases. Any of a number of model fields may be used with about the equivalent result, since the error inherent in this assumption is not likely to exceed a very few percent. As further examples, expressions for γ appropriate to fields that are based on the error function and other functions are included in the appendix.

Now let the origin of coordinates be placed over the estimated center of the local anomaly, and let the fraction t represent a rough estimate of the ratio of the magnitude of the local to the regional anomaly there. Let it be assumed that, for a given τ, the fractional residue at this point from the local field is R_I and that from the regional field is R_R, where R_L and R_R are chosen from among the mathematical representations of which examples are given in the appendix. Then the value of the function γ/g_R at the origin, where g_R is the fraction of g that is accounted as "regional," is approximately

$$\gamma(0)/g_R(0) \equiv R = R_R + tR_L. \tag{4}$$

Knowing the values of the parameters involved in the right-hand side of this expression, it then simply remains to solve for the value of τ which makes $R=1$.

As the origin is moved farther and farther from the center of the local anomaly, there will be less and less contribution to R from the local anomaly itself, while at the same time the value of R_R changes by very little. This means that, with nothing to compensate for the flattening of the regional field at the periphery of the local anomaly and beyond, the computed regional effect in this area will be less than it really should be and the residual anomaly will be correspondingly greater than it should. Consequently, to restore the residual anomaly to its true proportions, a correction for this effect should be applied to the results.

Since tR_L is usually very small, its decay will be practically linear; therefore the correction may be made by interpolating from the difference between the value of γ at a given point and the value given by the function R_R; or alternatively, if the point lies near the estimated "boundary" of the local anomaly, between γ and the observed g.

APPLICATION TO AN ARTIFICIAL PROBLEM

Let us now perform an objective test of the correction principle developed thus far, on an artificial problem where the object of the test is to superpose two known gravitational fields and then to see how accurately they can be resolved by the smoothing function.

The regional field has rotational symmetry and its radial profile is shown in Figure 1. This profile has been chosen quite at random, and is not intentionally

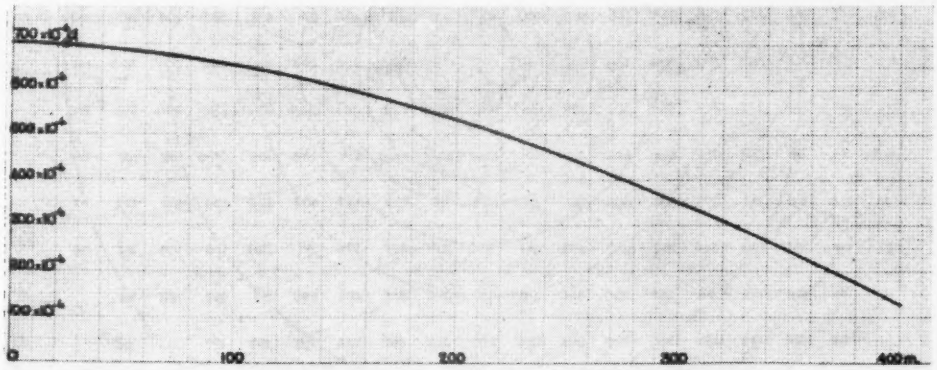


FIG. 1. Radial profile of the regional field.

related to any known structure or formula. The local anomaly is the field due to a tilted rectangular block $20\times30\times50$ meters, having a relative density of 1 gm/cm^3, whose center lies at a depth of 40 meters. (See Grant, 1952, p. 351 for geometry.) The anomaly field is shown in Figure 2. Figure 3 shows the composite field, with the local anomaly superposed on the flank of the regional anomaly. The center of the block lies 198 meters from the origin of the regional field along a line at 45° with the N-S axis.

Maximum gradient methods applied to the local anomaly give a value of 54.6 meters for the depth to the equivalent point source so that $\bar{z}\cong5$ if $s=10$ meters; for the regional anomaly, a value of about 470 meters is obtained for this depth, so that $\bar{r}\cong50$ and $\cos\theta\cong0.9$. Profiles through the local anomaly indicate a value for t of about $+1/3$. The function R defined by equations (4), (11) and (18) is then found to have a value 1.02 for $\tau\cong1/90$. In practice, a value of about 1.02 is preferred to 1 in order to compensate for the fact that contouring by interpolating linearly between stations tends to make the contour lines too small in circumference, thereby making zonal estimates of g systematically low.

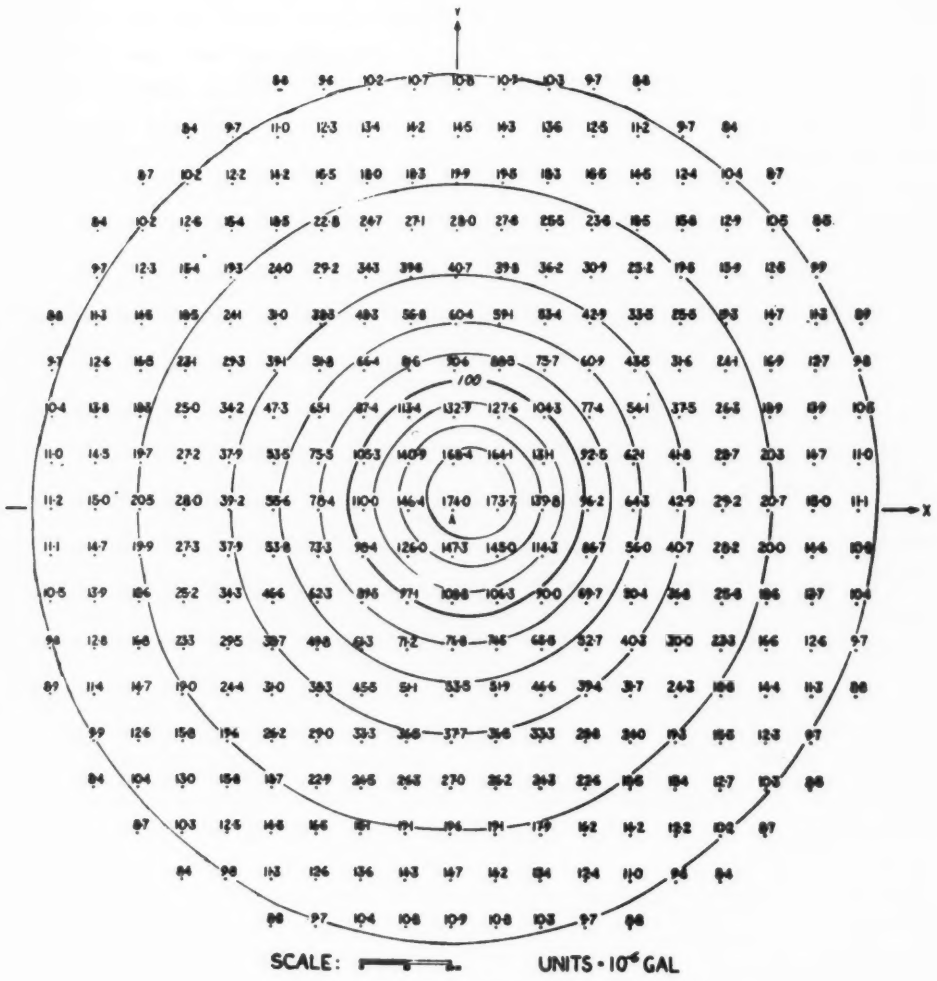


FIG. 2. The local field.

Figure 4 shows the template that is used in the computations, drawn to the same scale as Figure 3. The regional effect has been computed at a number of points along the profile XY, and Table II shows the comparison with the true regional field at these points. The second line of the table gives the values of γ yielded by the template, and the third illustrates the agreement that is obtained

TABLE II

Point No.	1	4	6	7	8	9	10	12	13
True Regional	621	607	573	555	534	512	490	439	412
$\bar{g}$	604	595	569	553	534	512	489	434	405
Computed Regional	623	609	575	555	534	513	491	438	410

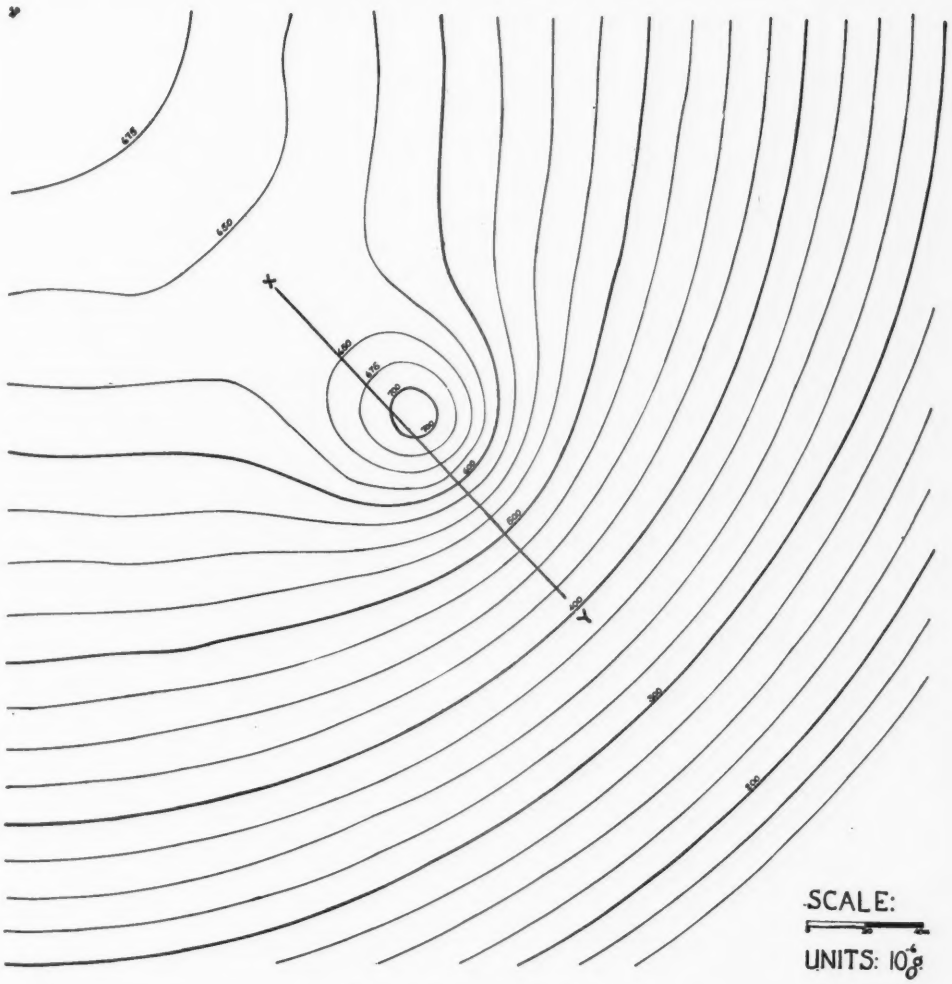


FIG. 3. The composite field.

when a linear correction based on calculated differences at the end points is applied. The XY profile of the residual anomaly and of the actual local field, shown together in Figure 5, demonstrate the almost perfect separation that is achieved.

EXTENSION OF THE THEORY TO FINITE RANGES

The foregoing example invites a considerable amount of confidence in the theory developed thus far, but clearly the amount of mechanical labor involved in making the computations is altogether prohibitive. Furthermore, if such large and unwieldy templates were applied to practical problems, they undoubtedly would pick up effects from neighboring local disturbances, and this to a large extent would vitiate the advantage in accuracy that should be gained by their

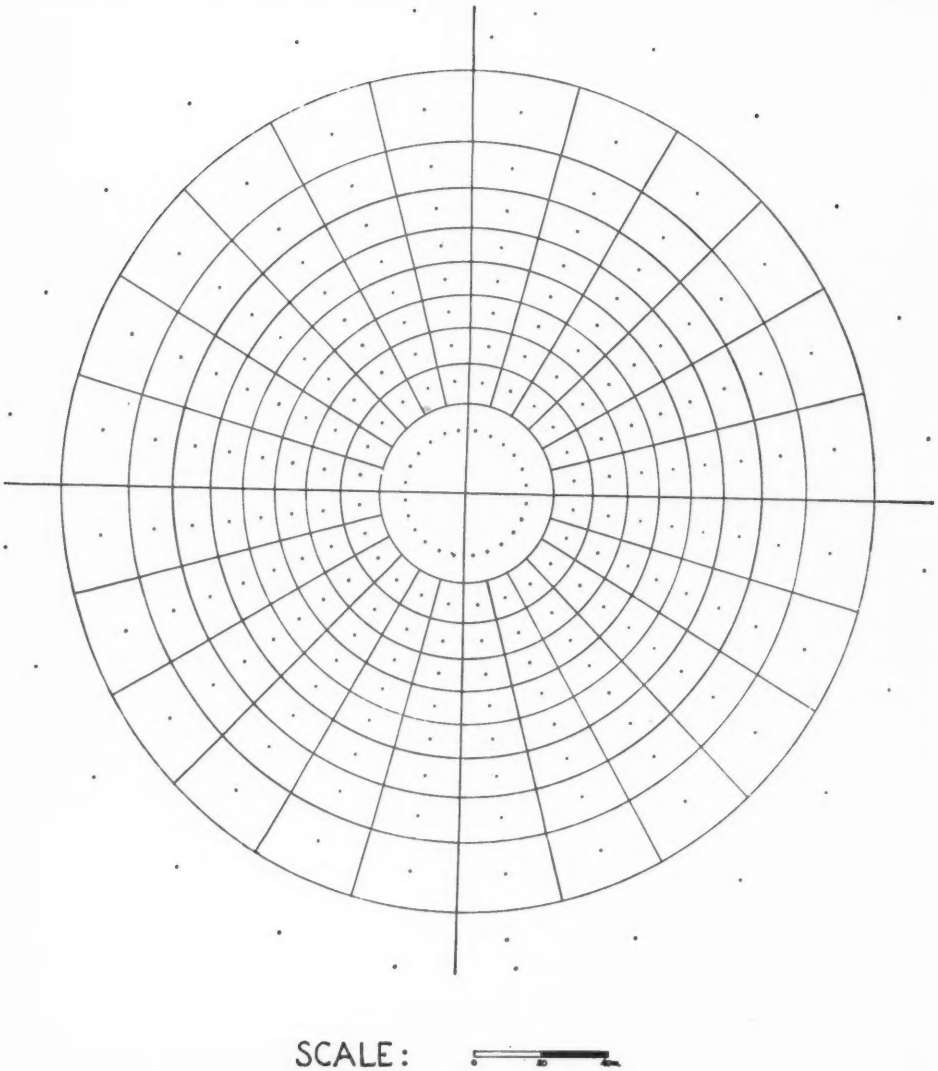


FIG. 4. Template used in the computations.

use. What is needed, therefore, is a means for converting equation (1) from an infinite to a finite integral with arbitrary limits which may be chosen to suit the requirements of the problem at hand. This may be done through the theory of Fourier transforms, provided equation (1) can be written as a Fourier integral. The clue to the solution consists in writing $1/4kt$ for β; then (1) becomes the general solution of the equation of diffusion (Carslaw and Jaeger, 1947, §17).

$$\nabla^2\psi = \frac{1}{k}\frac{\partial\psi}{\partial t} \tag{5}$$

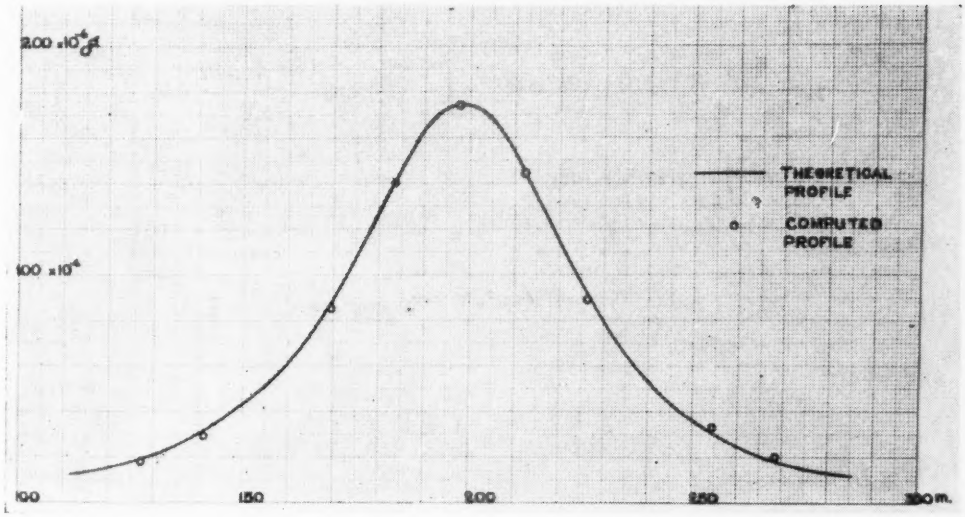


FIG. 5. XY profiles of the residual anomaly and of the local field.

over an infinite plane, where $g(x, y)$ is the initial value of ψ.

Two Dimensions:

When g depends upon one coordinate only, equation (5) has a particular integral

$$e^{-k\nu^2 t - i\nu x}. \tag{6}$$

If $g(x)$ is defined in the range $-X \leqq x \leqq X$ and satisfies Dirichlet's conditions (which obviously it must), then it may be expanded into the Fourier series

$$g(x) = \sum_{n=0}^{\infty} a_n \cos \frac{(2n+1)\pi}{2X} x,$$

where

$$a_n = \frac{1}{X} \int_{-X}^{X} g(\xi) \cos \frac{(2n+1)\pi}{2X} \xi d\xi.$$

Therefore equation (6) is a solution of equation (5) in the finite range when $\nu = (2n+1)\pi/2X$, and thus the general solution is

$$\psi(x, t) = \sum_{n=0}^{\infty} a_n e^{-[(2n+1)^2\pi^2 k t]/4X^2} \cdot \cos \frac{(2n+1)\pi}{2X} x,$$

whence it follows that

$$\gamma(x) = \sum_{n=0}^{\infty} a_n e^{-[(2n+1)^2\pi^2]/16X^2} \cdot \cos \frac{(2n+1)\pi}{2X} x.$$

Therefore

$$\gamma(0) = \frac{1}{X}\sum_{n=0}^{\infty} e^{-[(2n+1)^2\pi^2]/16\beta X^2}\cdot \int_{-X}^{X} g(\xi)\cos\frac{(2n+1)\pi}{2X}\xi d\xi,$$

$$= \int_{-X}^{X} g(\xi_1)\lambda(\xi_1)d\xi_1, \tag{7}$$

where

$$\lambda(\xi_1) = \frac{1}{X_1}\sum_{n=0}^{\infty} e^{-[(2n+1)^2\pi^2]/16\beta X_1^2}\cos\frac{(2n+1)\pi}{2X_1}\xi_1$$

and where

$$\xi = \xi_1 s, \qquad X = X_1 s.$$

Three Dimensions

When g depends upon two coordinates, equation (5) written in polar coordinates, becomes

$$\frac{\partial^2\psi}{\partial r^2} + \frac{1}{r}\cdot\frac{\partial\psi}{\partial r} + \frac{1}{r^2}\cdot\frac{\partial^2\psi}{\partial\theta^2} = \frac{1}{k}\frac{\partial\psi}{\partial t},$$

and this has a particular integral

$$e^{-k\alpha^2 t}\cdot J_n(\alpha r)e^{in\theta}.$$

If $g(r, \theta)$ is defined in the range $0 \leqq r \leqq R$, then it may be expanded into a Fourier-Bessel series (Watson, 1944, ch. 18.)

$$g(r, \theta) = \sum_{n=0}^{\infty}\sum_{s=1}^{\infty} A_{n,s}e^{in\theta}\cdot J_n(\alpha_s r),$$

where $\alpha_1, \cdots \alpha_s,$ are the positive roots of

$$J_n(\alpha R) = 0,$$

and where

$$A_{0,s} = 1/\pi R^2[J_0'(\alpha_s R)]^2\cdot\int_0^R\int_{-\pi}^{\pi} g(\rho, \phi)J_0(\alpha_s\rho)\rho d\phi d\rho$$

$$A_{n,s} = 2/\pi R^2[J_n'(\alpha_s R)]^2\cdot\int_0^R\int_{-\pi}^{\pi} g(\rho, \phi)J_n(\alpha_s\rho)e^{-in\phi}\rho d\phi d\rho.$$

Therefore, the general solution of equation (5) in $(0, R)$ is

$$\psi(r, \theta, t) = \sum_{n=0}^{\infty}\sum_{s=1}^{\infty} A_{n,s}e^{-k\alpha_s^2 t}\cdot J_n(\alpha_s r)e^{in\theta},$$

from which it follows that

$$\gamma(r, \theta) = \sum_{n=0}^{\infty} \sum_{s=1}^{\infty} A_{n,s} e^{-\alpha_s^2/4\beta} J_n(\alpha_s r) \cdot e^{in\theta}.$$

Hence

$$\gamma(o) = \sum_{s=1}^{\infty} 1/\pi R^2 [J_1(\alpha_s R)]^2 \cdot e^{-\alpha_s^2/4\beta} \int_0^R \cdot \int_{-\pi}^{\pi} g(\rho, \phi) J_0(\alpha_s \rho) \rho d\phi d\rho$$

$$= \int_0^R g(\rho_1) \Lambda(\rho_1) d\rho_1 \tag{8}$$

where

$$\Lambda(\rho_1) = 2\rho_1/R_1^2 \cdot \sum_{s=1}^{\infty} e^{-\alpha_s^2/4\tau} J_0(\alpha_s \rho_1)/[J_1(\alpha_s R_1)]^2$$

and where

$$\rho = \rho_1 s, \qquad R = R_1 s.$$

The integrals (7) and (8) may be evaluated with the aid of templates in the same way as (2) and (3). The weighting functions, however, now depend upon the values chosen for X or R, and must be tabulated accordingly; but both series are so powerfully convergent that two or three terms are usually sufficient to give 3-figure accuracy. Examples are illustrated in Figures 6 and 7, in which are

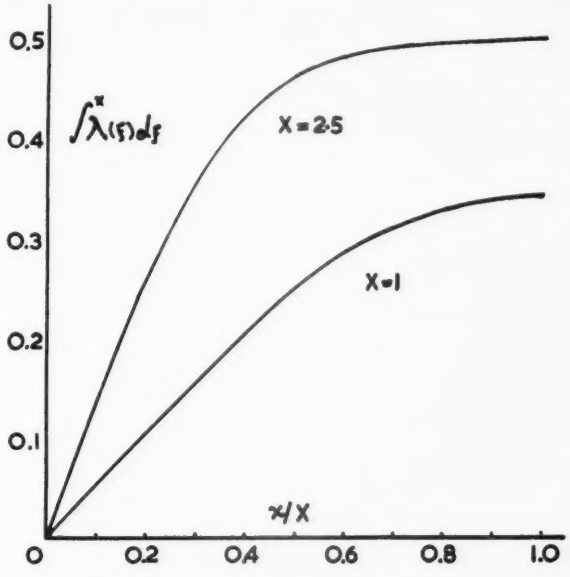


FIG. 6. Weighting functions for one-dimensional integration.

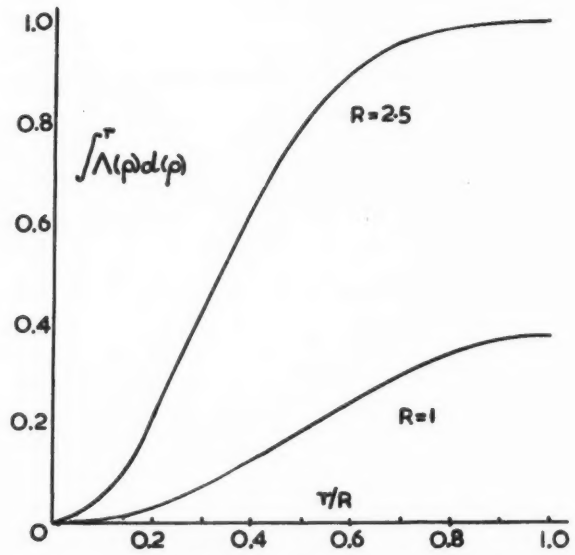


FIG. 7. Weighting functions for two-dimensional integration.

shown the weighting functions corresponding to terminal values for X and R of 1 and 2.5. (One might do the tabulation for a few such standard values and keep the results on file.) The tabulations may be carried out for $\tau = 1$ and converted to any other value in the same way as before.

While it might be interesting to repeat the previous exercise using a finite range, the value of such a demonstration would scarcely justify the labor involved, since it is clear that in theory the method ought to produce the same result for the finite as for the infinite range. Thus the calculations would amount merely to a numerical check on Fourier's integral theorem.

APPLICATION TO A GRAVITY SURVEY

As an illustration of the practical application of these methods, the example chosen is a gravity survey conducted over a salt dome structure in the South Houston field, Texas. The reason for the choice is that this survey has already been made the subject of an exhaustive study of the averaging methods most widely practiced (Griffin, 1949) and thus there is available a ready comparison of results. Figure 8 is the gravity map of the South Houston field, reprinted from the paper by Griffin. Clearly, the regional field in this area is of a two-dimensional sort.

Figure 9 shows a profile of the gravity through the section XY, laid upon a theoretical curve that seems to give a reasonably good fit to the regional background. This curve is the profile of the field due to a horizontal line at a depth of 7 miles. Rule of thumb methods indicate a depth of about 1.4 miles for the point source that gives the best approximation to the profile of the local anomaly,

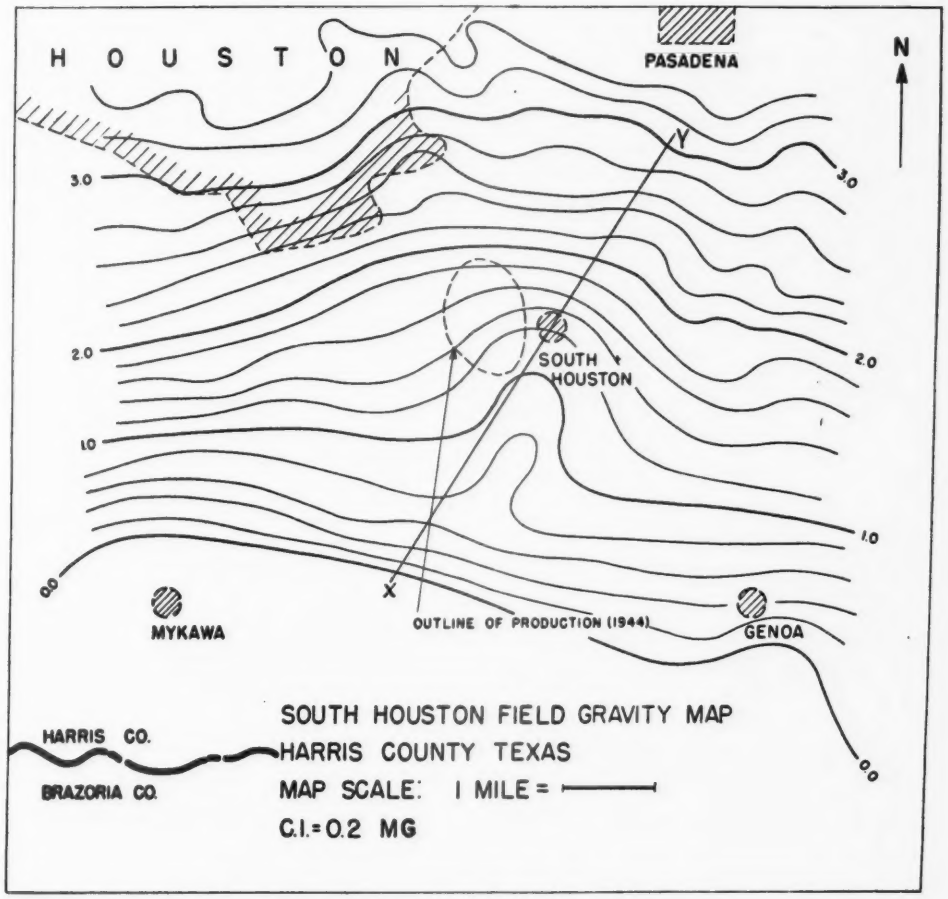


FIG. 8. Gravity map of the South Houston field and adjacent area. Contour interval=0.2 milligal.

and the fraction t appears to have a value of about 1/6. These are the values used in equations (10), (15), and (4) in order to find the best value to use for τ, corresponding to whatever value may be chosen for X.

One of the noteworthy features of the present method is that the results obtained are quite independent of the size of the diagram used in making the computations. This is inherent in the theory, but a practical demonstration might be interesting nevertheless. Accordingly, templates were drawn with outer radii of 1 unit and of 2.5 units (where the unit is the equivalent of 1 mile), and used in the manner prescribed for calculating residuals. Contoured maps of the residual anomalies obtained with these templates are shown separately in Figures 10 and 11, respectively. There are slight differences, but only such as are just perceptible to the eye and which are unlikely to affect quantitative interpretations. In one case, the maximum residual is -0.68 milligal and in the other,

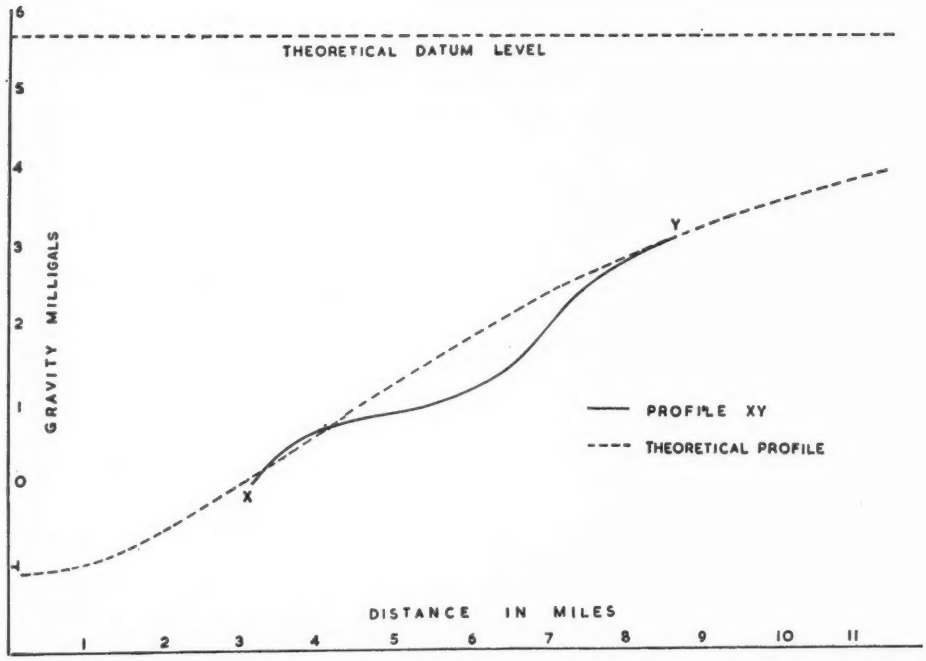


FIG. 9. Showing the *XY* profile of Figure 8 superimposed on the profile of the field due to a horizontal line at depth 7 miles.

−0.69 milligal. Since the size of the diagram is the only quantity the choice of which lies wholly at the discretion of the interpreter, it follows that the residual map prepared from a given set of data by one individual should compare with that prepared by another, thus removing one of the major defects of averaging. Because of this, the residual map must have physical significance, and it probably gives a reasonably illustrative picture of the local anomaly.

These maps might be studied profitably in conjunction with the residual maps prepared by Griffin. Extrapolating from Figure 4 of his paper, it would appear that averaging around a circle 2.75 units in radius would produce about the same result for the maximum residual; but on the other hand, there is no real similarity in general appearance to any of his residual maps, possibly excepting his Figure 15, which was prepared by averaging at 60° intervals around a circle 3 units in radius. Structural contours on the top of the South Houston dome have been published by Eby (1945) (the area of production delineated in Figures 8, 10, and 11 lies off the northwest flank of the dome), and in size, shape and position the anomalies shown in Figures 10 and 11 and in Griffin's Figure 15 are compatible with the known dimensions of the salt. Griffin's other maps give some indication of the salt, but his Figure 15 seems to be by a considerable margin the most articulate expression. Arguments relating to the interpretation of these maps, however, lie beyond the scope of this paper.

AN APPENDIX OF MATHEMATICAL FORMULAE

In choosing suitable mathematical models to represent the regional and local anomalies for the purpose of choosing τ, it is useful to have ready at hand the corresponding expressions for the functions R_L and R_R for use in equation (4). Some examples are given here, but they are by no means exhaustive.

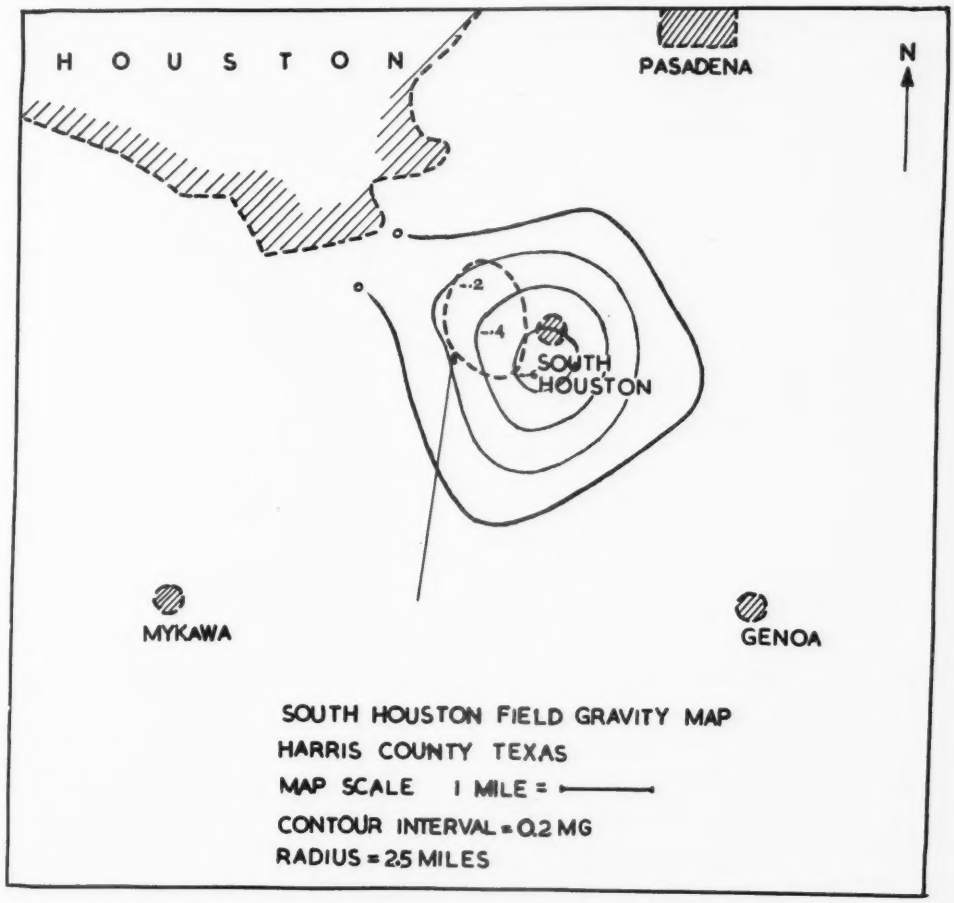


FIG. 10. Residual map prepared by using a diagram of outer radius 2.5 units.

It is assumed that the range of integration is such that it may be considered infinite without serious error in evaluating the contributions from local effects. Thus equations (2) and (3) are used for this purpose rather than (7) and (8), with the proviso that the model chosen to represent g_L (which is $g-g_R$) must be bounded throughout the infinite range. No such restriction need apply to g_R, however, since in evaluating the regional contribution finite ranges only are considered.

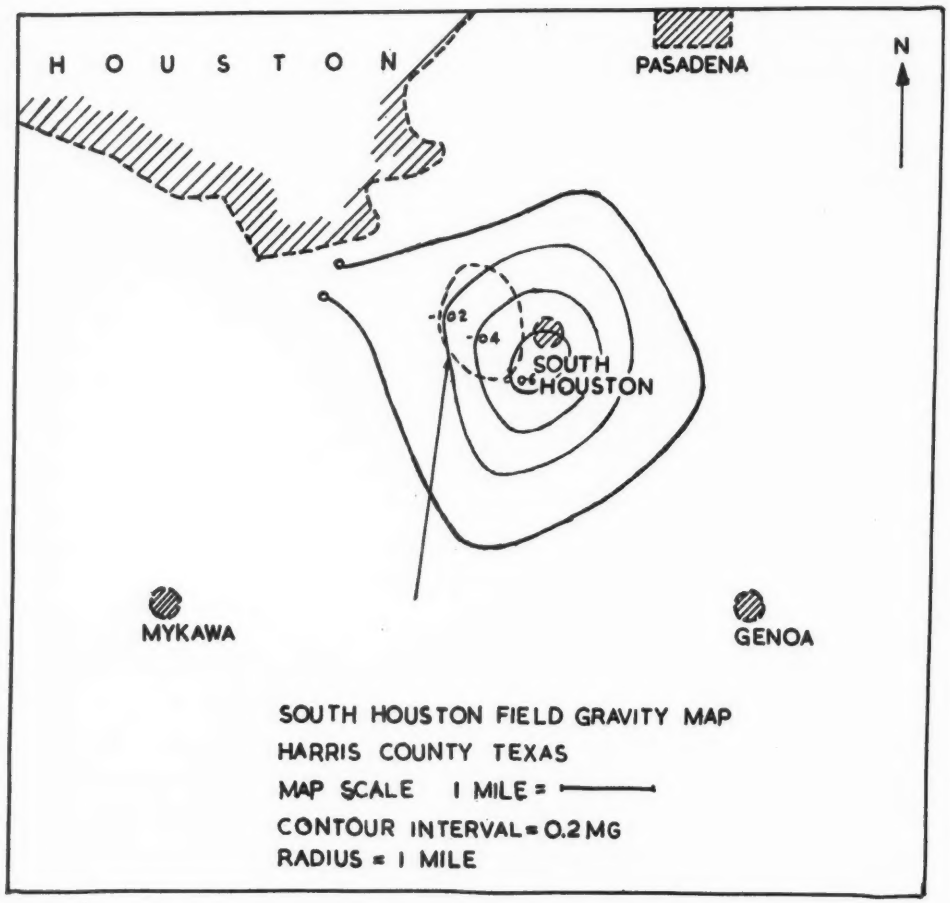


FIG. 11. Residual map prepared by using a diagram of outer radius 1 unit.

The Local Field

(1) A line source at depth $\bar{z}$ directly below the origin of coordinates, $g_L(x) = 2k\bar{z}/(x^2+\bar{z}^2)$.

$$\gamma_L(0) = 2k\bar{z}\sqrt{\frac{\beta}{\pi}}\int_{-\infty}^{\infty}\frac{e^{-\beta\xi^2}d\xi}{\xi^2+\bar{z}^2}$$

$$= 2k\bar{z}\beta^{1/2}\cdot e^{\beta\bar{z}^2}\int_{\beta}^{\infty} e^{-\beta\bar{z}^2}\cdot\beta^{-1/2}d\beta,$$

$$= 2k\pi^{1/2}\beta^{1/2}e^{\beta\bar{z}^2}\cdot\operatorname{erfc}(\sqrt{\beta\bar{z}^2}).$$

Therefore

$$R_L \equiv \gamma_L(0)/g_L(0) = \pi^{1/2}\mu^{1/2}e^{\mu}\operatorname{erfc}(\sqrt{\mu}), \qquad \mu = \tau\bar{z}_1^2. \tag{9}$$

(2) A point source at a depth $\bar{z}$ directly below the origin of coordinates, $g_L(r)=k\bar{z}/(r^2+\bar{z}^2)^{3/2}$.

(i) One-dimensional integration:

$$\gamma_L(0) = k\bar{z}\sqrt{\frac{\beta}{\pi}}\int_{-\infty}^{\infty}\frac{e^{-\beta\xi^2}d\xi}{(\xi^2+\bar{z}^2)^{3/2}}\cdot$$

$$= -2k\sqrt{\frac{\beta}{\pi}}\frac{\partial}{\partial\bar{z}}\int_0^{\infty}\frac{e^{-\beta\xi^2}d\xi}{\sqrt{\xi^2+\bar{z}^2}}$$

$$= -k\sqrt{\frac{\beta}{\pi}}\frac{\partial}{\partial\bar{z}}\cdot e^{\beta\bar{z}^2/2}K_0\left(\frac{\beta\bar{z}^2}{2}\right)$$

where K_0 is the Bessel function of the second kind with imaginary argument. Therefore

$$R_L = \pi^{-1/2}\mu^{3/2}e^{\mu/2}\left[K_1\left(\frac{\mu}{2}\right)-K_0\left(\frac{\mu}{2}\right)\right], \qquad \mu=\tau\bar{z}_1^2. \tag{10}$$

(ii) Two-dimensional integration:

$$\gamma_L(0) = 2k\bar{z}\beta\int_0^{\infty}\frac{e^{-\beta\rho^2}\cdot\rho d\rho}{(\rho^2+\bar{z}^2)^{3/2}}$$

$$= 2k\beta - 2k\beta^2\bar{z}e^{\beta\bar{z}^2}\cdot\int_{\bar{z}^2}^{\infty}e^{-\beta T}\cdot T^{-1/2}\cdot dT, \qquad T=\rho^2+\bar{z}^2.$$

$$= 2k\beta - 4k\beta^{3/2}\bar{z}e^{\beta\bar{z}^2}\cdot\int_{\sqrt{\beta\bar{z}^2}}^{\infty}e^{-\chi^2}d\chi, \qquad \chi^2=\beta T.$$

Thus

$$R_L = 2\mu - 4\mu^{3/2}e^{\mu}\cdot\operatorname{erfc}(\sqrt{\mu}), \qquad \mu=\tau\bar{z}_1^2. \tag{11}$$

(3) $g_L(r)=k/(r^2+\alpha^2)$.

(i) One dimensional integration: see (9)

(ii) Two-dimensional integration:

$$\gamma_L(0) = 2k\beta\cdot\int_0^{\infty}\frac{e^{-\beta\rho^2}\cdot\rho d\rho}{\rho^2+\alpha^2},$$

$$= k\beta e^{\beta\alpha^2}\cdot\int_{\beta}^{\infty}e^{-\beta\alpha^2}\cdot\beta^{-1}d\beta,$$

hence

$$R_L = \mu e^{\mu}Ei(\mu), \qquad \mu=\tau\alpha_1^2. \tag{12}$$

(4) $g_L(\bar{\tau}) = ae^{-b\bar{r}^2}$.

(i) One-dimensional integration:

$$\gamma_L(0) = a\beta^{1/2}\pi^{-1/2}\int_{-\infty}^{\infty} e^{-(b+\beta)\xi^2}d\xi, \qquad = \frac{a\sqrt{\beta}}{\sqrt{b+\beta}},$$

so that

$$R_L = \sqrt{\frac{\tau}{b_1+\tau}}, \qquad b_1 = bs^2. \tag{13}$$

(ii) Two-dimensional integration:

$$\gamma_L(0) = 2\,a\beta\cdot\int_0^{\infty} - e^{(b+\beta)\rho^2}\cdot\rho d\rho = \frac{a\beta}{b+\beta},$$

Therefore

$$R_L = \tau/(b_1+\tau), \qquad b_1 = bs^2. \tag{14}$$

The Regional Field

(1) A line source at depth $\bar{z}$ and at a distance $\bar{r}(=\sqrt{\bar{x}^2+\bar{z}^2})$ from the origin of coordinates; $g_R(x) = 2k\bar{z}/(x-\bar{x})^2+\bar{z}^2)$

Then

$$\gamma_R(0) = \frac{2k\bar{z}}{X}\sum_{n=0}^{\infty} e^{-[(2n+1)^2\pi^2]/16\beta X^2}\int_{-X}^{X}\frac{\cos\left\{(2n+1)\pi/2X\right\}\xi d\xi}{(\xi-\bar{x})^2+\bar{z}^2}.$$

The integration may be performed by an operational technique, by noting that

$$\frac{1}{(\xi-\bar{x})^2+\bar{z}^2} = e^{-\xi\bar{p}}\cdot\frac{1}{\bar{p}^2},$$

where

$$\bar{p} = \frac{d}{d\bar{x}}.$$

Thus

$$\gamma_R(0) = \frac{2\pi k\bar{z}}{X^2}\sum_{n=0}^{\infty}(-)^n\cdot e^{-[(2n+1)^2\pi^2]/16\beta X^2}\cdot\frac{2n+1}{(2n+1)^2\pi^2/4X^2+\bar{p}^2}\cosh X\bar{p}\cdot\frac{1}{\bar{r}^2}$$

$$= -\frac{2\pi k\bar{z}}{X^2}e^{\alpha\bar{p}^2}\int^{\alpha} d\alpha e^{-\alpha\bar{p}^2}\left(\sum_{n=0}^{\infty}(-)^n\cdot(2n+1)e^{-[(2n+1)^2\pi^2\alpha]/4X^2}\right)$$

$$\cdot\cosh X\bar{p}\cdot\frac{1}{\bar{r}^2}, \qquad \alpha = \frac{1}{4\beta}.$$

Series such as the one in brackets may be summed by applying the theory of Mellin transforms. The analysis is rather involved and depends upon certain properties of the generalized Zeta-function (Whittaker & Watson, 1947, ch. XIII), but the general procedure is clearly laid down by Macfarlane (1949). It turns out that

$$R_R \equiv \gamma_R(0)/g_R(0) = \bar{z}^2 e^{\bar{p}^2/4\beta} \cdot [\sinh X\bar{p}/X\bar{p} - \coth X\bar{p}]\,\frac{1}{\bar{r}} \qquad (15)$$

and when $X \to \infty$,

$$R_R \to \bar{z}^2 e^{\bar{p}^2/4\beta} \cdot \frac{1}{\bar{r}^2}\,. \qquad (16)$$

(2). A point source at a distance $\bar{r}(\bar{\theta}, \bar{\phi})$ from the origin of coordinates,

$$\begin{aligned} g_R(\rho, \phi) &= \left[-\frac{1}{\rho}\,\frac{\partial}{\partial(\cos\theta)} \cdot \frac{k}{\sqrt{\bar{r}^2 + \rho^2 - 2\bar{r}\rho\cos\epsilon}} \right]_{\theta=\pi/2}, \qquad \epsilon = \widehat{\bar{r},\rho} \\ &= \left[-\frac{1}{\rho} \cdot \frac{\partial}{\partial(\cos\theta)} \cdot \frac{k}{\bar{r}} \sum_{l=0}^{\infty} \left(\frac{\rho}{\bar{r}}\right)^l P_l(\cos\epsilon) \right]_{\theta=\pi/2}, \qquad \rho < \bar{r}, \\ &= \frac{k}{\bar{r}\rho} \sum_{l=0}^{\infty} \left(\frac{\rho}{\bar{r}}\right)^l \sum_{m=-l}^{m=l} \frac{(l - |m|)!}{(l + |m|)!}\, e^{im(\phi-\bar{\phi})} P_l^{|m|}(\cos\bar{\theta}) P_l^{|m|\prime}(0). \end{aligned}$$

Then

$$\begin{aligned} \gamma_R(0) = \frac{k}{\pi R^2 \bar{r}} \sum_{s=1}^{\infty} e^{-\alpha_s^2/4\beta} \frac{1}{[J_1(\alpha_s R)]^2} \sum_{l=0}^{\infty} \frac{1}{\bar{r}^l} \int_0^R \rho^l J_0(\alpha_s \rho) d\rho \\ \cdot \sum_{m=-l}^{n=l} \frac{(l - |m|)!}{(l + |m|)!} P_l^{|m|}(\cos\bar{\theta}) P_l^{|m|\prime}(0) \cdot \int_{-\pi}^{\pi} e^{im(\phi-\bar{\phi})} d\phi. \end{aligned}$$

Integration with respect to ϕ removes all terms except those in which $m = 0$. Also $P_l'(0) = lP_{l-1}(0) = 0$, for $l = 0, 2, 4, \cdots, 2k$, hence

$$\begin{aligned} \gamma_R(0) &= \frac{2k}{\bar{r}^2 R^2} \sum_{s=1}^{\infty} e^{-\alpha_s^2/4\beta} \cdot \frac{1}{[J_1(\alpha_s R)]^2} \cdot \sum_{k=0}^{\infty} \frac{2k+1}{\bar{r}^{2k}} P_{2k+1}(\cos\bar{\theta}) \\ &\quad \cdot P_{2k}(0) \cdot \int_0^R \rho^{2k+1} J_0(\alpha_s \rho) d\rho. \\ &= \frac{2k\cos\bar{\theta}}{R\bar{r}^2} \sum_{s=1}^{\infty} e^{-\alpha_s^2/4\beta} \cdot \frac{1}{J_1(\alpha_s R)} \cdot \sum_{k=0}^{\infty} c_k \cdot \left(\frac{R}{\bar{r}}\right)^{2k} \\ &\quad \cdot \sum_{r=0}^{k} (-)^r \cdot \frac{2^{2r} \cdot (k!)}{\alpha_s^{2r+1}[(k-r)!]^2} \cdot \frac{1}{R^{2r}} \end{aligned}$$

where

$$c_k = (2k+1)k!P_{2k}(0)P_{2k+1}(\cos\bar{\theta})/\cos\bar{\theta}.$$

Thus

$$R_R \equiv \gamma_R(0)/g_R(0) = \sum_{k=0}^{\infty} c_k \cdot \left(\frac{R}{\bar{r}}\right)^{2k}\left(\sum_{r=0}^{k}(-)^r \cdot \frac{2^{2r}\cdot k!}{[(k-r)!]^2 R^{2r}}\chi_r(\beta)\right), \tag{17}$$

where

$$\chi_r(\beta) = \frac{2}{R}\sum_{s=1}^{\infty}\frac{1}{\alpha_s^{2r+1}}\cdot e^{-\alpha_s^2/4\beta}\cdot\frac{1}{J_1(\alpha_s R)}$$

$$\simeq \sum_{k=0}^{\infty} c_k\left\{\frac{1}{(\beta\bar{r}^2)^k} - e^{-\beta R^2}\sum_{r=0}^{k}\frac{1}{(k-r)!}\left(\frac{R^2}{\bar{r}^2}\right)^{k-r}\cdot\frac{1}{(\beta\bar{r}^2)^r}\right\}$$

for ordinary values of β, so that if $\beta R^2 \gg 1$, (i.e., if $R\to\infty$) then

$$R_R \simeq 1 + \frac{c_1}{\nu} + \frac{c_2}{\nu^2} + \cdots, \quad \nu = \tau\bar{r}_1^2. \tag{18}$$

(3). A paraboloidal field, $g_R(\rho,\phi) = a - b(\rho^2 + \rho_0^2 - 2\rho\rho_0\cos(\phi_0 - \phi))$.

$$\gamma_R(0) = [a - b(R^2+\rho_0^2)]\cdot\frac{2}{R}\sum_{s=1}^{\infty}\frac{1}{\alpha_s}e^{-\alpha_s^2/4\beta}\cdot\frac{1}{J_1(\alpha_s R)}$$

$$+\frac{8b}{R}\sum_{s=1}^{\infty}\frac{1}{\alpha_s^3}\cdot e^{-\alpha_s^2/4\beta}\cdot\frac{1}{J_1(\alpha_s R)},$$

which for reasonably larger values of R,

$$\simeq [a - b(R^2+\rho_0^2)](1 - e^{-\beta R^2}) + bR^2 Ei_1(\beta R^2) - b/\beta\cdot e^{-\beta R^2},$$

so that

$$(a - b_1\rho_{01}^2)R_R \simeq a - b_1(R_1^2 + \rho_{01}^2) + b_1 R_1^2 Ei_1(\tau R_1^2), \tag{19}$$

where

$$b_1 = bs^2, \qquad \rho_0 = \rho_{01}s, \qquad R = R_1 s.$$

Similar formulas may be obtained for the parabolic-cylindrical field $g_R(\xi) = a - b(\xi - \xi_0)^2$ and others, but since the inventory is endless no really useful purpose can be served by attempting to be exhaustive.

In conclusion, a word about the use of these formulas: One does not always know, of course, if in fact local anomalies are present, and sometimes the regional correction is carried out simply for the purpose of finding out. In such cases one may put $t=0$ in (4) and choose that value for τ which one estimates should alter the regional field at the most by, say, about 5%; such a value would be certain

to locate local disturbances of any appreciable magnitude. Furthermore, in order to estimate this τ, it should not always be necessary to go through the laborious calculations involved in the use of these algebraic models, for experience should often be quite a satisfactory judge in problems of this nature. Thus, at the risk of a further repetition of this point, the proper role of these formulas is that of a guide and not that of a rigorous arbiter.

ACKNOWLEDGMENT

This problem originally was undertaken while the writer was an associate of the Geophysics Laboratory, Department of Physics, at the University of Toronto, and was revised and completed while he was a visiting associate of the Department of Geodesy and Geophysics at the University of Cambridge. It is a pleasure to thank both of these institutions for their hospitality and their indulgence, and also the Imperial Oil Company of Canada, through whose consideration and interest his year of association with the Geophysical Laboratory at Toronto was made possible.

REFERENCES

Carslaw, H. S. and Jaeger, J. C., 1947, Conduction of heat in solids: Oxford, Oxford University Press.

Grant, F. S., 1952, Three dimensional interpretation of gravitational anomalies: Geophysics, v. 17, p. 344–364.

Griffin, W. Raymond, 1949, Residual gravity in theory and practice: Geophysics, v. 14, p. 39–56.

Macfarlane, G. G., 1949, Application of Mellin transforms to the summation of slowly-convergent series: Phil. Mag., v. 40, p. 188–197.

Skeels, D. C., 1947, Ambiguity in gravity interpretation: Geophysics, v. 12, p. 43–56.

Watson, G. N., 1944, A treatise on the theory of Bessel functions: Cambridge, Cambridge Univ. Press.

Weatherburn, C. E., 1952, Mathematical statistics: Cambridge, Cambridge Univ. Press.

Whittaker, E. T. and Watson, G. N., 1947, Modern analysis, revised edition: Cambridge, Cambridge Univ. Press.

Vajk, R., 1951, Regional correction of gravity data: Geofisica Pura e Applicata, v. 19, p. 129–143.

SOME GEOMETRICAL PROPERTIES OF RESIDUAL MAPS*

CHARLES A. SWARTZ†

ABSTRACT

From well known mathematical theory it can be demonstrated that most contour maps may be considered to be built up by the superposition of a double infinity of elementary undulating surfaces, each of which has the form of a horizontal sinusoidally corrugated sheet, infinite in extent. These elementary surfaces may have all possible wave lengths, orientations, amplitudes, and phases. Several examples are given of simple mosaic-type composite maps built up by combining only two such elementary surfaces in different ways. These resemble geophysical contour maps in many significant respects.

Residual maps are often prepared by using a template procedure for computing the residual value at any point as a linear combination of several neighborhood values interpolated from the original map. An expression is derived for the Fourier transform of any residual map prepared in this way. This transform gives the amplitude spectrum of the residual map in terms of the amplitude spectrum of the original map and the geometry of the template pattern. It is applied to the special case of an original map of the two-component mosaic variety mentioned above. The results are presented quantitatively in the form of attenuation, or filter, curves which show the amplitudes of the residual anomalies for various sizes and shapes of original anomalies, and for several different residual templates.

The geometrical significance of "second derivative" maps is discussed, and it is shown that they may be prepared by a process which is a limiting case of applying a residual template pattern of very simple type.

Attenuation curves are presented for several kinds of residual templates when applied to an idealized original contour map consisting of a single anomaly of various shapes. These filter curves are very similar to those for original maps of the simple mosaic type. It is concluded that, since most geophysical maps may be considered to be of a kind intermediate between these two extreme types, the attenuation curves given here may be useful for designing residual templates which will have desired selective characteristics.

INTRODUCTION

In the process of interpreting geophysical maps contoured on data which represent potential field measurements, such as gravity and magnetic, it is customary to prepare so-called residual maps. An almost unlimited variety of such maps can be constructed (Griffin, 1949; Elkins, 1951; Agocs, 1951). They are variously known as residual maps, derived maps, second derivative maps, etc. The use to which they are put, as well as the appraisal of their worth, varies considerably among the interpreters who are charged with the responsibility of gleaning from them as much pertinent information as possible. In spite of varying opinions as to details, however, there appears to be little doubt that they do serve a very useful purpose in the overall evaluation of the geophysical data.

It is the purpose of this paper to examine, from the standpoint of the geometry involved, some of the methods which are in common use for constructing residuals and to point out a few relationships between their geometrical characteristics and those of the original maps from which they were derived. This information may serve as a guide for predicting what can be accomplished by preparing residual maps, and possibly also as an aid in their interpretation.

* Manuscript received by the Editor August 7, 1953.

† United Geophysical Co., Inc., Pasadena, Calif.

THE GEOMETRICAL COMPOSITION OF CONTOUR MAPS

For the purpose of describing mathematically a contour map, we will choose rectangular coordinates in the plane of the map with positive x axis in the east direction and positive y axis in the north direction. If we let G designate the value of the observed quantity at any point in this plane, the function $G(x, y)$ will specify the map completely. Then, by making use of the Fourier integral theorem in two variables we can write[1]

$$G(x, y) = (1/4\pi^2)\int_{-\infty}^{\infty} d\omega \int_{-\infty}^{\infty} d\psi \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G(\xi, \eta)e^{i\omega(x-\xi)}e^{i\psi(y-\eta)}d\xi d\eta \qquad (1)$$

or

$$G(x, y) = (1/4\pi^2)\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} T^*G(x, y)e^{i(\omega x+\psi y)}d\omega d\psi, \qquad (2)$$

where

$$T^*G(x, y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G(\xi, \eta)e^{-i(\omega\xi+\psi\eta)}d\xi d\eta. \qquad (3)$$

In equation (3), $T^*G(x, y)$ is the Fourier transform of $G(x, y)$ and is a function of ω and ψ only. In general it is a complex function. Also it is evident from equation (2) that any map is completely specified by giving either the function $G(x, y)$ or its transform $T^*G(x, y)$.

The geometrical significance of equation (2) may be brought out more clearly by writing it in its real form after making the following substitutions:

$$T^*G(x, y) = P(\omega, \psi) - iQ(\omega, \psi) \qquad (4)$$

$$e^{i(\omega x+\psi y)} = \cos(\omega x + \psi y) + i\cdot\sin(\omega x + \psi y). \qquad (5)$$

The result is

$$G(x, y) = (1/4\pi^2)\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}[P^2(\omega, \psi) + Q^2(\omega, \psi)]^{1/2} \cdot\sin[\omega x + \psi y + \phi(\omega, \psi)]d\omega d\psi, \qquad (6)$$

where

$$\phi = \tan^{-1}[P(\omega, \psi)/Q(\omega, \psi)]. \qquad (7)$$

[1] It is assumed that $G(x, y)$ is single valued, and that it satisfies the usual mathematical limitations as regards convergence of its integral, etc. Gravity and magnetic data are necessarily single valued. If a map is multiple-valued in places, as, for example, a structure map involving thrust faulting or overturned structures, the overlapping portions may be detached and treated separately as single valued surfaces. The convergence restrictions are satisfied by any map of finite size met with in practice if $G(x, y)$ is assumed equal to zero everywhere outside the mapped area.

Equation (6) implies that the surface $G=G(x, y)$, representing practically any contour map whatever, may be considered to be made up of the superposition of a double infinity of simple elementary surfaces, $g=g(x, y)$, whose individual equations are given by the integrand of equation (6), namely,

$$g(x, y) = (1/4\pi^2)\left[P^2(\omega, \psi) + Q^2(\omega, \psi)\right]^{1/2} \sin\left[\omega x + \psi y + \phi(\omega, \psi)\right]. \tag{8}$$

The form of these elementary surfaces is illustrated in Figure 1. They are sinusoidal plane wave, or corrugated, surfaces of infinite extent in both directions in the x, y plane. The geometrical characteristics of each such elementary wave surface are as follows:

$$\text{amplitude} = a(\omega, \psi) = (1/4\pi^2)\left[P^2(\omega, \psi) + Q^2(\omega, \psi)\right]^{1/2} \tag{9}$$

$$\text{phase angle} = \phi(\omega, \psi) = \tan^{-1}\left[P(\omega, \psi)/Q(\omega, \psi)\right] \tag{10}$$

$$\text{wave length} = L(\omega, \psi) = 2\pi(\omega^2 + \psi^2)^{-1/2} \tag{11}$$

$$\text{angle of orientation} = \alpha(\omega, \psi) = \tan^{-1}(-\omega/\psi). \tag{12}$$

These relationships are easily derived, or are evident from the geometry of Figure 1.

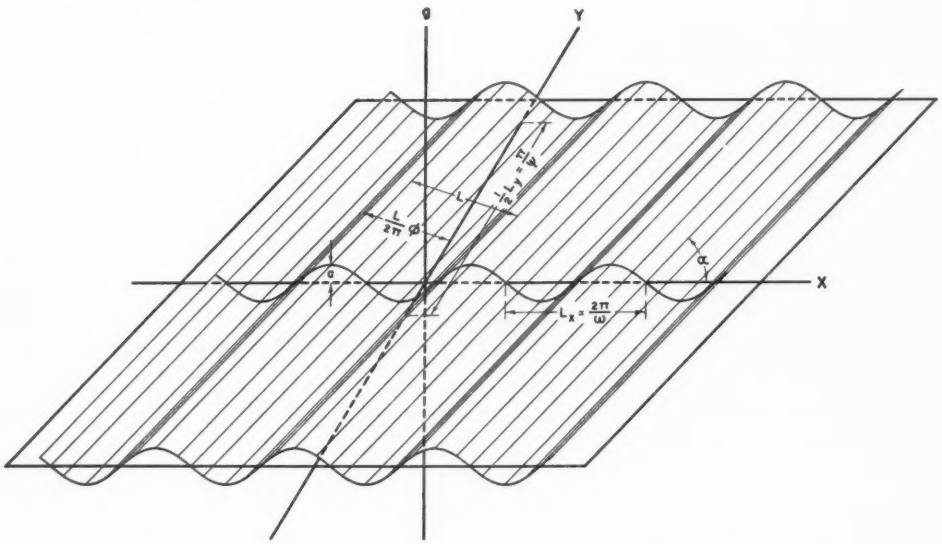


FIG. 1. Diagram illustrating geometry of an elementary wave surface whose equation is $g(x, y)=a \sin(\omega x+\psi y+\phi)$.

Thus, by assigning all possible pairs of values to the two parameters, ω and ψ, it is seen from equations (11) and (12) that elementary wave surfaces of all possible wave lengths and orientations will be generated. Then, by deriving the transform $T^*G(x, y)$ from equation (3), and thereby determining the real functions $P(\omega, \psi)$ and $Q(\omega, \psi)$ in equation (4), the proper amplitude, $a(\omega, \psi)$, and

phase, $\phi(\omega, \psi)$, can be given to each elementary wave surface by equations (9) and (10) so that when they are all added together they reproduce the arbitrary map surface $G=G(x, y)$.

The parameters ω and ψ, associated with any particular elementary surface, are the apparent angular rates of change, measured in radians per unit of length, along the x and y axes respectively. The apparent wave lengths as measured along the two axes are, therefore,

$$L_x = 2\pi/\omega \quad \text{and} \quad L_y = 2\pi/\psi. \tag{13}$$

Furthermore, if we designate the absolute value, or the modulus, of the transform $T^*G(x, y)$ by $\left| T^*G(x, y) \right|$ then it is evident from equation (9) that

$$a(\omega, \psi) = (1/4\pi^2) \cdot \left| T^*G(x, y) \right|. \tag{14}$$

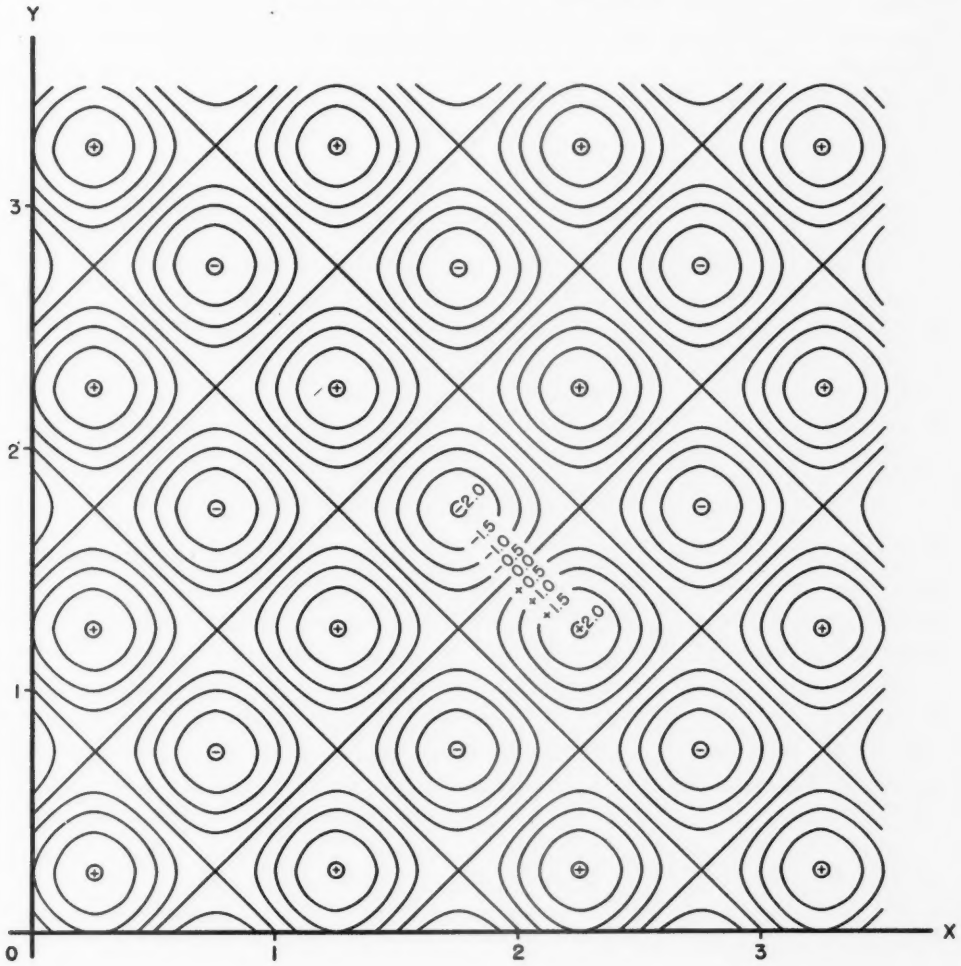


FIG. 2. Contours on two component map surface $G=\sin 2\pi x+\sin 2\pi y$.

That is, the amplitude $a(\omega, \psi)$ of the oscillations of any component elementary wave surface characterized by the parameters ω and ψ is $1/4\pi^2$ times the absolute value of the Fourier transform of $G(x, y)$. As already pointed out, the transform also determines the phase angle $\phi(\omega, \psi)$ according to equation (10).

These very general geometrical properties of surfaces are all well known.

SYNTHESIS OF TYPE CONTOUR MAPS

The procedures discussed above must, of course, be carried out analytically. However, the reverse process of synthesizing a rather complex contour map from a few elementary surfaces may be done graphically and can be illustrated by several examples.

The simplest example is the elementary surface of Figure 1. In this figure the waves, or corrugations, are aligned at an angle α with the x axis. If $\omega = 0$ then, by equation (12), $\alpha = 0$ and the orientation is parallel to the x axis. If $\psi = 0$, it is parallel to the y axis.

As a second example add two elementary surfaces, one parallel to the y axis, the other parallel to the x axis, each of unit amplitude and wave length, and with phase angle zero. The equation for the combined surface is

$$G = \sin 2\pi x + \sin 2\pi y. \tag{15}$$

This surface is contoured in Figure 2. It is a mosaic of alternate high and low features, all of them being identical in relief, size, and shape. Their shape is generally square in outline.

For a third example combine two elementary surfaces, one parallel to the y axis, of unit amplitude and wave length, and zero phase angle, the other parallel to the x axis, of unit amplitude, of wave length three, and zero phase angle. The equation of the combined surface is

$$G = \sin 2\pi x + \sin (2\pi/3)y. \tag{16}$$

It is contoured in Figure 3, and consists of a regular pattern of alternate positive and negative anomalies, uniform in size, shape and relief. In this case the individual anomalies are diamond shaped with their major axes oriented in a north-south direction and three times as long as the minor axes.

The fourth example is a combination of two elementary surfaces, one parallel to the y axis, of unit amplitude and wave length, and zero phase angle; and the other parallel to the x axis, with amplitude equal to one half, with unit wave length, and zero phase angle. Its equation is

$$G = \sin 2\pi x + (1/2) \sin 2\pi y. \tag{17}$$

The contours of this surface, shown in Figure 4, are again a uniform pattern of high and low anomalies each of which is elongated in the north-south direction. The zero contour lines are sinuous and aligned in a general north-south direction.

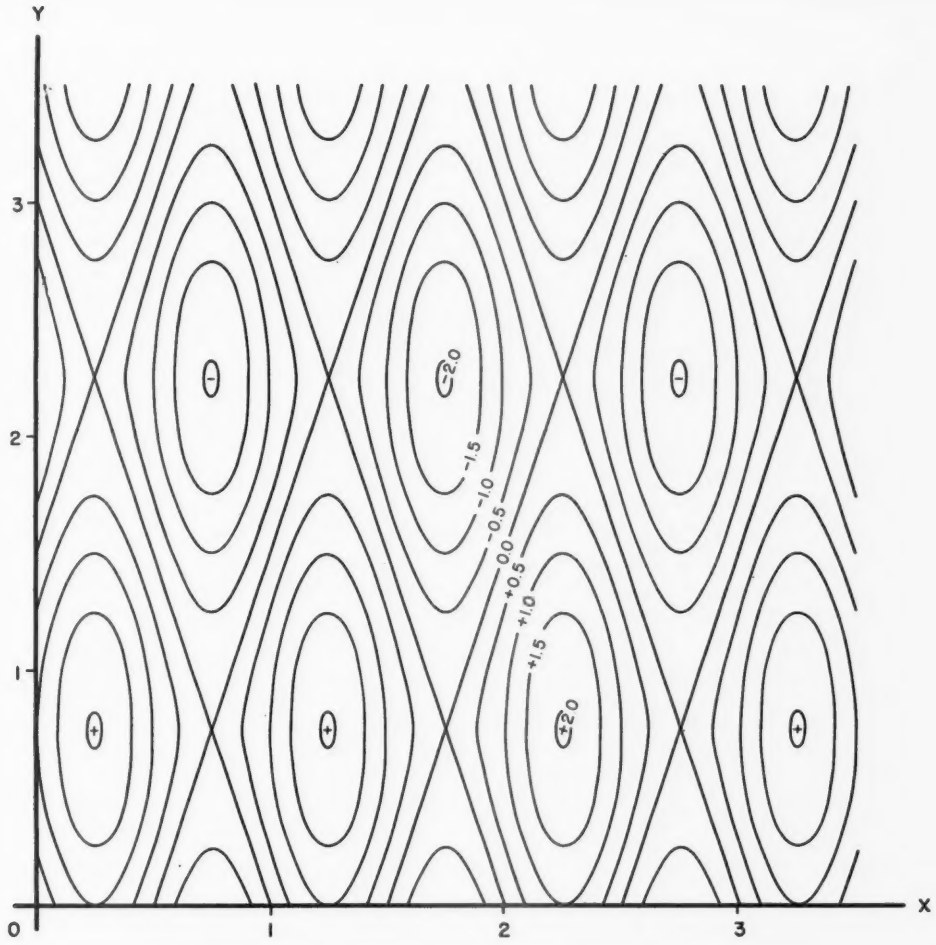


FIG. 3. Contours on two component map surface $G=\sin 2\pi x+\sin (2\pi/3)y$.

Figure 5 is still another example of a combination of two elementary surfaces. In this case one is aligned parallel to the y axis, of unit amplitude and wave length, and zero phase angle. The other is oriented at an angle of 45° with respect to the x axis, is of unit amplitude and wave length, and zero phase angle. The individual anomalies comprising the resulting mosaic are rectangular in shape, are nearly 2.5 times as long as they are wide, and their axes are oriented at an angle of 67.5° with respect to the x axis. The equation of the composite surface is

$$G = \sin 2\pi x + \sin \sqrt{2}\,\pi(x - y). \tag{18}$$

These few examples are illustrations of the synthetic process. By adding more than two elementary surfaces, contour maps of greater complexity can be pro-

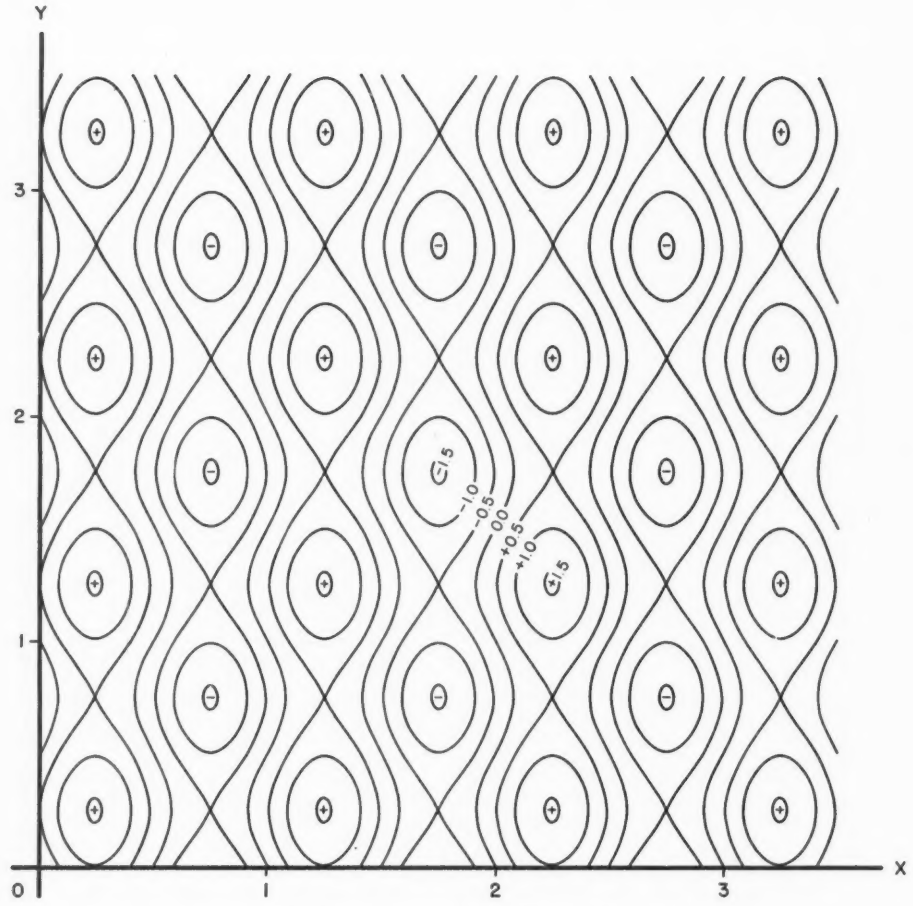


FIG. 4. Contours on two component map surface $G=\sin 2\pi x+\frac{1}{2}\sin 2\pi y$.

duced. Eventually, by including a sufficiently large number of elementary surfaces with the proper phase, amplitude, wave length, and orientation relationships, any arbitrary map can be duplicated.

PREPARATION OF RESIDUAL MAPS

Residual maps are usually prepared by replacing each individual value on a contour map by a new one derived by combining, in some specific manner, a number of values in the surrounding neighborhood. For instance, as shown in Figure 6, the value at the center of the circles may be replaced by the average of the several values on one of the circles themselves. Or, it may be replaced by some combination of the averages on two or more different circles. After each value on the original contour map has been replaced by its new value these new values are contoured to produce the "residual map."

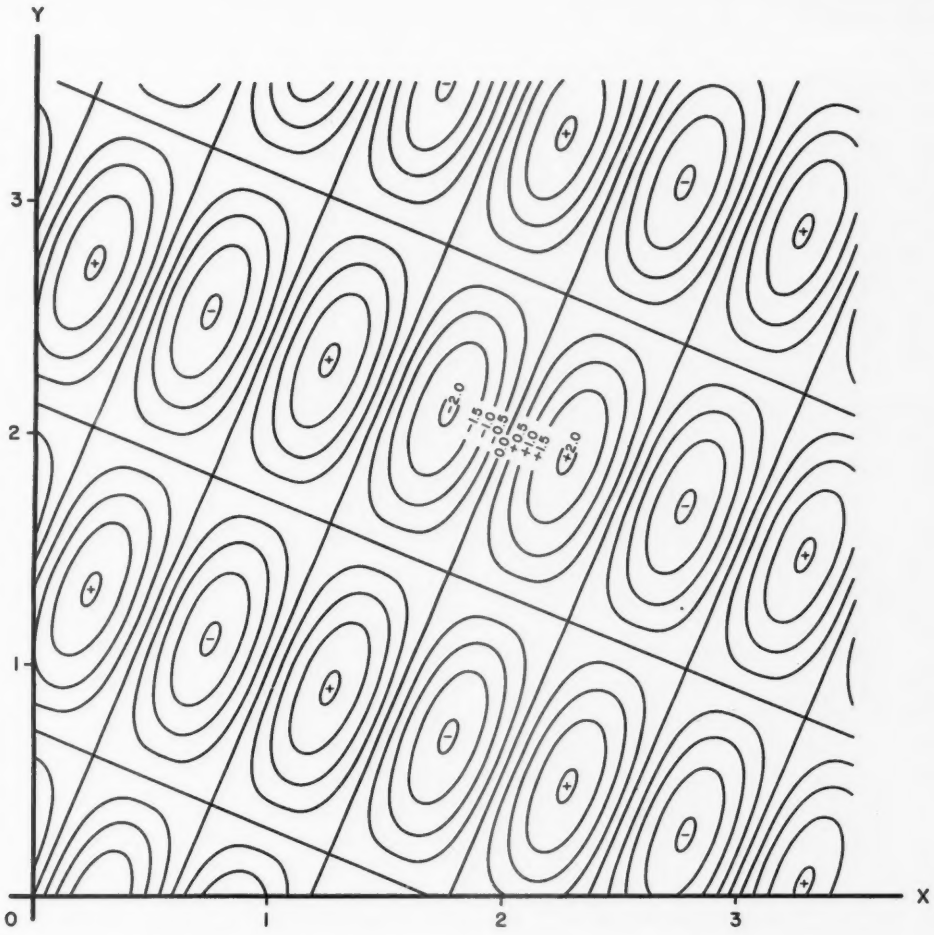


FIG. 5. Contours on two component map surface $G=\sin 2\pi x+\sin\sqrt{2}\pi(x-y)$.

Instead of replacing the value at C by a simple average we may wish to replace it with the difference between the value at C and the average on one or more circles. In this case it is evident that the operation is equivalent to determining the departure of the value at C from the average value in its neighborhood, a large neighborhood if large circles are used or a small neighborhood if small circles are used. Or, we might use the difference between a large neighborhood average and a small neighborhood average with analogous results.

Figure 7 illustrates similar patterns based on square and octagonal arrays rather than circular ones. These may be employed in a manner similar to the circles, and, moreover, the squares lend themselves readily to areal averages. Thus, with the squares it is feasible to compute areal averages or integrations over large or small neighborhoods, or combinations of them. And, of course,

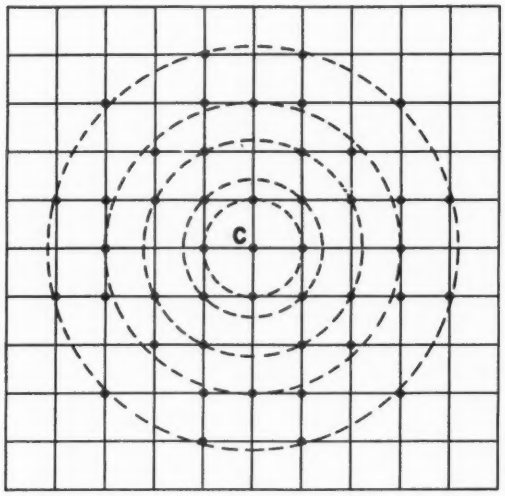


FIG. 6. Examples of circular residual template patterns.

combinations of squares, circles, and octagons, or other geometrical patterns may be used.

In order to carry through these operations on a routine basis it is customary to lay out the desired patterns in the form of a template on transparent material, or on opaque material with cutouts. This template, when centered, in succession, on each point of the original map, frames the correct set of values to be used in the computations. This is easy if the values on the original map are located on a uniformly spaced grid pattern. If the data are not so arranged an interpolated grid sheet may be prepared at the required spacing. An alternate method is to interpolate individually the values required at each point of the template as its

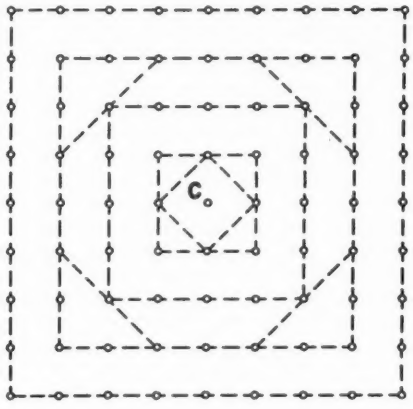


FIG. 7. Examples of square and octagonal type residual template patterns.

center is moved from one position to another. The uniformly interpolated grid is usually preferred.

The residual maps obtained as a result of these various types of operations may be similar in appearance to the original map or they may be quite different, depending on the sizes and combinations of the patterns for the templates. By choosing the proper sizes and combinations of the patterns the selective effects of the templates may be predetermined. That is, they may be made to accentuate those anomalies on the original map which are of such a size as to be desirable, and to attenuate those which are not. In this way they may often be made to serve a useful purpose.

ANALYSIS OF RESIDUAL MAPS

In all of the methods discussed here, the operations consist of the computation of linear combinations of values in the neighborhood of a point. Because they are linear operations they can be readily treated analytically, and quantitative results may be deduced regarding their selective characteristics.

On the original map the value of G at any point x, y is $G(x, y)$. At any neighboring point $x+h$, $y+k$ the value of G is $G(x+h, y+k)$. If we let $T^*G(x+h, y+k)$ be the Fourier transform of $G(x+h, y+k)$ then it is evident from equation (3) that

$$T^*G(x+h, y+k) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G(\xi+h, \eta+k)e^{-i(\omega\xi+\psi\eta)}d\xi d\eta \tag{19}$$

or, letting $\xi+h=\xi'$ and $\eta+k=\eta'$

$$\begin{aligned} T^*G(x+h, y+k) &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G(\xi', \eta')e^{-i[\omega(\xi'-h)+\psi(\eta'-k)]}d\xi' d\eta' \\ &= e^{i(\omega h+\psi k)}T^*G(x, y). \end{aligned} \tag{20}$$

Equation (20) shows that the transform of $G(x+h, y+k)$ is the transform of $G(x, y)$ multiplied by the factor $e^{i(\omega h+\psi k)}$. Also, if we let $T^*[G(x+h_1, y+k_1) + G(x+h_2, y+k_2)]$ be the transform of the function inside the bracket then it is evident that

$$\begin{aligned} &T^*[G(x+h_1, y+k_1) + G(x+h_2, y+k_2)] \\ &\quad = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}[G(\xi+h_1, \eta+k_1) + G(\xi+h_2, \eta+k_2)]e^{-i(\omega\xi+\psi\eta)}d\xi d\eta \\ &\quad = [e^{i(\omega h_1+\psi k_1)} + e^{i(\omega h_2+\psi k_2)}]T^*G(x, y). \end{aligned} \tag{21}$$

In other words, the transform of the sum of the two functions $G(x+h_1, y+k_1)$ and $G(x+h_2, y+k_2)$ is the transform of $G(x, y)$ multiplied by the sum of the two factors $e^{i(\omega h_1+\psi k_1)}$ and $e^{i(\omega h_2+\psi k_2)}$. And, in general, if c_n is any constant, we can write

$$T^*[\sum c_n G(x + h_n, y + k_n)] = [\sum c_n e^{i(\omega h_n + \psi k_n)}] T^*G(x, y)$$
$$= F(\omega, \psi) T^*G(x, y) \tag{22}$$

where

$$F(\omega, \psi) = \sum c_n e^{i(\omega h_n + \psi k_n)}. \tag{23}$$

If we let $G'(x, y)$ be the residual map produced from any original map $G(x, y)$ by any of the methods we have discussed, i.e., by linear combinations of neighborhood values, we can write

$$G'(x, y) = \sum c_n G(x + h_n, y + k_n). \tag{24}$$

And from equation (22) it is seen that

$$| T^*G'(x, y) | = | F(\omega, \psi) | \cdot | T^*G(x, y) |. \tag{25}$$

This equation shows that the effect of making a residual map is to multiply $(1/4\pi^2) | T^*G(x, y)|$, the amplitude of each elementary surface comprising the original map, by the factor $|F(\omega, \psi)|$. In addition, equation (22) shows that the phase angle of each elementary surface is shifted by an amount equal to the phase angle of $F(\omega, \psi)$.

The function $F(\omega, \psi)$ is a function of the constants h_n, k_n, c_n which are determined by the geometry of the residual template used and the manner in which the values are combined. It is of the nature of an attenuation function, and, when it is known, the selective properties of the corresponding residual process may be predicted.

ATTENUATION CURVES FOR SEVERAL SIMPLE RESIDUAL PROCESSES

The above analysis may be illustrated by working out the details of a few simple types of residuals.

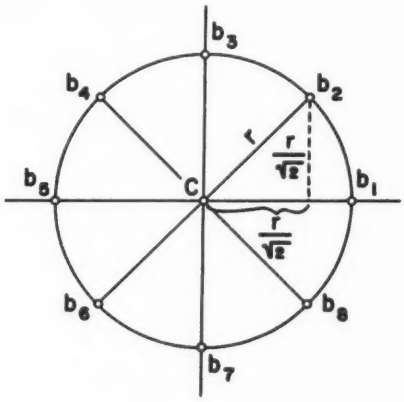


FIG. 8. Diagram used for deriving the attenuation function, $F(\omega, \psi)$, for a simple averaging process.

First, take the case where the residual value at any point C is merely the average of eight values distributed over a circle of radius r with the point C as center. The template pattern is shown in Figure 8.

For this pattern we have

$$F(\omega, \psi) = (1/8) \sum_{n=1}^{n=8} e^{i(\omega h_n + \psi k_n)}$$

$$= (1/8) \sum_{n=1}^{n=8} [\cos (\omega h_n + \psi k_n) + i \cdot \sin (\omega h_n + \psi k_n)]. \qquad (26)$$

Since the pattern is symmetrical, the second, or imaginary, term in the bracket is zero. As a consequence $F(\omega, \psi)$ is real and its phase angle is zero. As a matter of fact this will be true of all the residual templates with which we will be concerned here, as they will all be symmetrical. By substituting into equation (26) the values of h_n and k_n for the eight points on the circle of Figure 8 we get

$$F(\omega, \psi) = (1/4)[\cos r\omega + \cos (r\omega/\sqrt{2} + r\psi/\sqrt{2})$$
$$+ \cos r\psi + \cos (- r\omega/\sqrt{2} + r\psi/\sqrt{2})]. \qquad (27)$$

Thus, equation (27) gives the factor by which the amplitude of the elementary component wave surface, of parameters ω and ψ, in the original map surface, must be multiplied to give the amplitude of the corresponding component wave surface in the residual map, when the radius of the averaging circle is r. Also, since $F(\omega, \psi)$ is real, there is no phase shift.

As an example of a typical original contour map let us take one of the form illustrated by Figures 2 and 3. Its equation is given by

$$G(x, y) = \sin 2\pi x + \sin 2\pi y/q. \qquad (28)$$

It consists of two plane wave elementary surfaces, one oriented at right angles to the x axis of wave length unity, and another at right angles to the y axis of wave length q. The individual anomalies constituting the mosaic are elongated in the ratio q to 1. For this original contour map we then have[2]

$$\begin{aligned} \omega_1 &= 2\pi \qquad \psi_1 = 0 \\ \omega_2 &= 0 \qquad \psi_2 = 2\pi/q. \end{aligned} \qquad (29)$$

Then from equation (27)

$$F(\omega_1, \psi_1) = (1/4) \cos 2\pi r + (1/2) \cos \sqrt{2}\, \pi r + 1/4 \qquad (30)$$

[2] The map represented by equation (28) does not satisfy the convergence requirements for the existence of a Fourier transform defined by equation (3). However, it is evident that it possesses a discrete spectrum of two terms and that equation (27) is applicable to each of the two elementary component surfaces.

and

$$F(\omega_2, \psi_2) = (1/4) \cos 2\pi r/q + (1/2) \cos \sqrt{2}\, \pi r/q + 1/4. \tag{31}$$

Since the amplitude of each of the two component surfaces comprising the original map is unity, the amplitudes of the corresponding component surfaces of the residual map are given directly by equations (30) and (31). Moreover, when these two component surfaces are added together the amplitude of the resulting residual, defined as one half the total range of variation, is equal to the sum of the amplitudes of the two component surfaces. Thus if we let A' be the amplitude of the variations in the residual map we can write

$$A' = F(\omega_1, \psi_1) + F(\omega_2, \psi_2) = (1/4) \cos 2\pi r + (1/4) \cos 2\pi r/q + (1/2) \cos \sqrt{2}\, \pi r + (1/2) \cos \sqrt{2}\, \pi r/q + 1/2. \tag{32}$$

In other words, if we take a contour map of a mosaic type whose analytical expression is given by equation (28), and of which Figures 2 and 3 are typical examples, and if we produce from it a residual map by merely taking the average of eight points on a circle of radius r, then this residual map will consist of another mosaic of simple type anomalies whose amplitudes are given by equation (32), and of which Figure 4 is a typical example. It is evident from equation (32) that the amplitude, A', of the residual anomalies is a function of the radius, r, of the averaging circle, as well as of the ratio, q, of the length to the width of the individual anomalies comprising the original map.

For convenience in further discussion we will state here the following definitions:

(1) The relative width of the original anomalies is the ratio of their diagonal width to the diameter of the averaging circle.

(2) The shape factor of the original anomalies is the ratio of their length to their width, i.e. the quantity q.

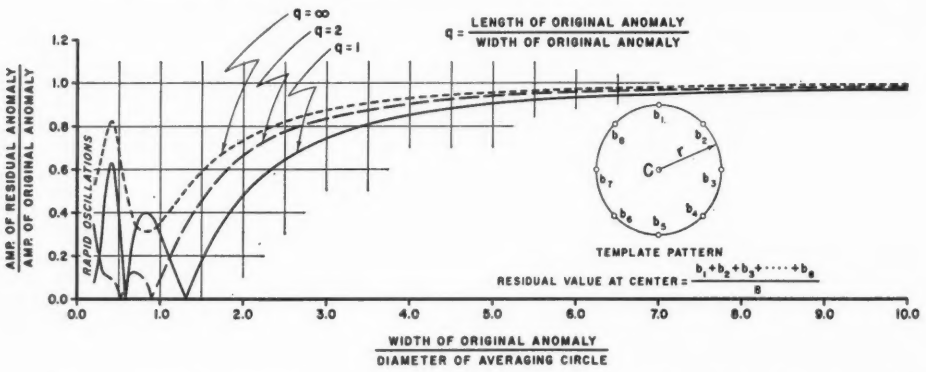


FIG. 9. Attenuation curves for a residual map prepared by averaging eight values on a circle of radius r on the original map, when the original map is of the general type illustrated by Figures 2 and 3.

(3) The normalized amplitude of the residual anomalies is the ratio of their amplitude to the amplitude of the original anomalies, i.e. the quantity $A'/2$, since the amplitude of the originals is equal to 2.

The curves of Figure 9 were obtained by plotting the normalized amplitude of the residual anomalies, i.e. $A'/2$ from equation (32), versus the relative width of the original anomalies, for values of q equal to 1, 2, and ∞. They show how the normalized amplitude of the residual anomalies varies with the relative width and the shape of the original anomalies, when the residuals are computed by a simple averaging process. From these curves it is seen that when the width of the original anomaly is more than three or four times the diameter of the averaging circle the amplitude of the residual anomaly is practically equal to that of the original. As the width of the original anomaly becomes smaller and approaches the diameter of the circle, the residual anomaly is greatly attenuated in amplitude. The amount of the attenuation depends somewhat on q, the shape factor of the original anomaly. As the relative width becomes still smaller, the filter curves begin to show rapid fluctuations or oscillations. And, theoretically, as the width approaches zero there will be an infinite number of these "resonant" oscillations but they will be finite in amplitude. From the practical standpoint, however, the oscillations are of no particular consequence since they are due to very small anomalies on the original map. On actual maps there is a finite lower limit to the size of the anomalies which are present and in which we are interested and, of course, the infinitely small ones do not exist.

These attenuation curves show quantitatively how this type of residual, resulting from a simple averaging process, tends to retain the larger anomalies and to discard the smaller ones.

As a second example of a simple type of residual map, consider the case in which the residual value at any point is the original value at that point minus the average of eight values on a circle of radius r. In this case we readily find that

$$F(\omega, \psi) = 1 - (1/4)[\cos r\omega + \cos (r\omega/\sqrt{2} + r\psi/\sqrt{2}) + \cos r\psi + \cos (-r\omega/\sqrt{2} + r\psi/\sqrt{2})]. \tag{33}$$

And if we assume, as before, that the original map is one whose analytical expression is given by equation (28), the amplitude A' of the residual anomalies is given by

$$A' = 3/2 - (1/4)\cos 2\pi r - (1/4)\cos 2\pi r/q - (1/2)\cos \sqrt{2}\,\pi r - (1/2)\cos \sqrt{2}\,\pi r/q. \tag{34}$$

The corresponding attenuation curves, obtained by plotting $A'/2$ of equation (34) versus $1/2r$, for values of q equal to 1, 2, and ∞, are shown in Figure 10. They again show how the amplitude of the residual anomaly varies with the relative width and the shape of the original anomaly. These curves are peaked in the

vicinity of the point where the width of the original anomaly is equal to the diameter of the averaging circle. The maximum value of the normalized amplitude is 1.4. For greater widths the amplitude is rapidly attenuated, while for smaller sizes the attenuation fluctuates rapidly because of repeated resonant effects.

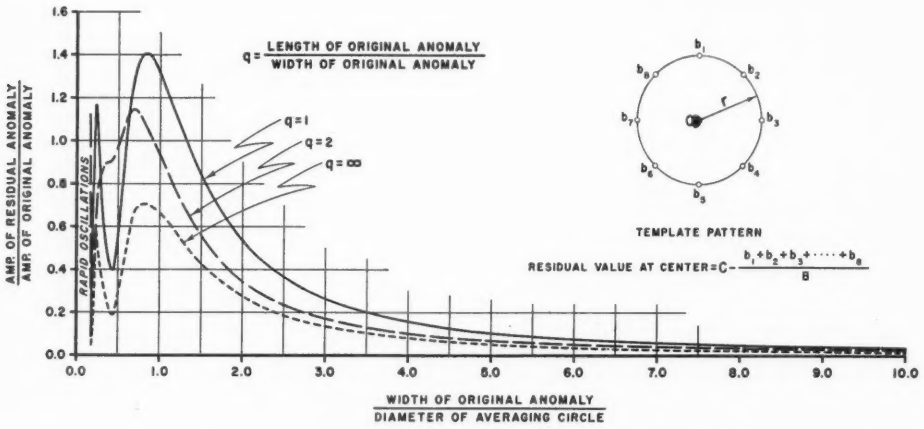

q = LENGTH OF ORIGINAL ANOMALY / WIDTH OF ORIGINAL ANOMALY
q=1
q=2
q=∞
RAPID OSCILLATIONS
AMP. OF RESIDUAL ANOMALY / AMP. OF ORIGINAL ANOMALY
WIDTH OF ORIGINAL ANOMALY / DIAMETER OF AVERAGING CIRCLE
TEMPLATE PATTERN
RESIDUAL VALUE AT CENTER = C − (b1+b2+b3+⋯+b8)/8

FIG. 10. Attenuation curves for a residual map prepared by subtracting the average of eigh values on a circle of radius r, on the original map, from the value at the center, when the original map is of the general type illustrated by Figures 2 and 3.

For a third example let the residual process consist of subtracting the average of eight points on a circle of radius $3r$ from the average of eight points on a circle of radius r. In this case we find

$$A' = (1/4)(\cos 2\pi r - \cos 6\pi r + \cos 2\pi r/q - \cos 6\pi r/q) + (1/2)(\cos \sqrt{2}\,\pi r - \cos 3\sqrt{2}\,\pi r + \cos \sqrt{2}\,\pi r/q - \cos 3\sqrt{2}\,\pi r/q). \quad (35)$$

The corresponding attenuation curves, for original maps of the same type that we have previously assumed, are shown in Figure 11. They are peaked in the range where the original anomaly is approximately one and one fourth times as wide as the mean diameter of the two averaging circles. The maximum value, for $q=1$, is about 1.1. Fairly rapid attenuation takes place at greater widths, whereas, for the smaller sizes, repeated minor maxima occur.

The fourth, and last, example is the case where the residual value at any point is the original value at that point minus the average of eight values on a square of half-side r. The residual amplitude is found to be

$$A' = 3/2 - (3/4)\cos 2\pi r - (3/4)\cos 2\pi r/q. \quad (36)$$

The attenuation curves are given in Figure 12. As one would expect, they are very similar to the curves for the circular template of Figure 10. They are peaked

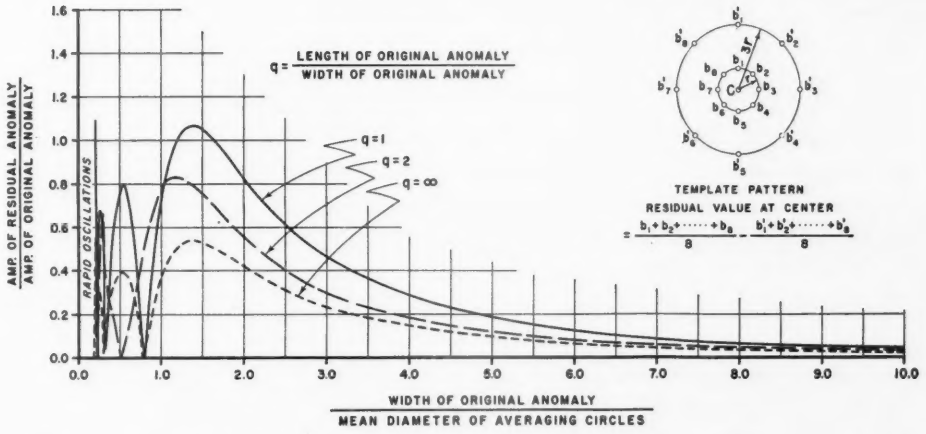

AMP. OF RESIDUAL ANOMALY / AMP. OF ORIGINAL ANOMALY
q = LENGTH OF ORIGINAL ANOMALY / WIDTH OF ORIGINAL ANOMALY
q=1
q=2
q=∞
RAPID OSCILLATIONS
TEMPLATE PATTERN
RESIDUAL VALUE AT CENTER
WIDTH OF ORIGINAL ANOMALY / MEAN DIAMETER OF AVERAGING CIRCLES

FIG. 11. Attenuation curves for a residual map prepared by subtracting the average of eight values on a circle of radius $3r$, on the original map, from the average of eight values on a circle of radius r, when the original map is of the general type illustrated by Figures 2 and 3.

at approximately the same point, but the optimum value for the square, when $q=1$, is equal to 1.5.

These few examples illustrate the general form of the attenuation curves for several simple but common procedures for preparing residual maps. Similar attenuation curves for any other residual method which consists of a linear combination of neighboring values can be readily constructed. It is to be emphasized that they have been derived here only for original maps which consist of a uniform grid or mosaic of simple anomalies such as are illustrated in Figures 2 and 3. In a number of respects, however, these mosaics can be considered to be

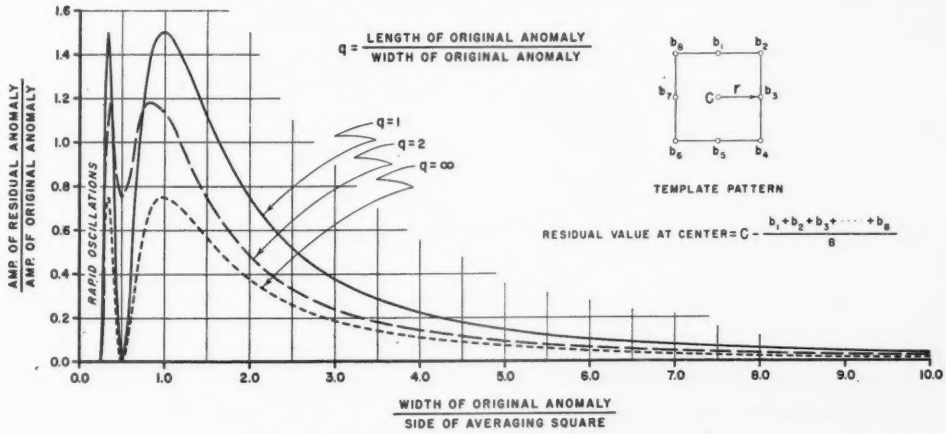

AMP. OF RESIDUAL ANOMALY / AMP. OF ORIGINAL ANOMALY
q = LENGTH OF ORIGINAL ANOMALY / WIDTH OF ORIGINAL ANOMALY
q=1
q=2
q=∞
RAPID OSCILLATIONS
TEMPLATE PATTERN
RESIDUAL VALUE AT CENTER = C − (b1+b2+b3+ ··· +b8)/8
WIDTH OF ORIGINAL ANOMALY / SIDE OF AVERAGING SQUARE

FIG. 12. Attenuation curves for a residual map prepared by subtracting the average of eight values on a square of half-side r, on the original map, from the value at the center, when the original map is of the general type illustrated by Figures 2 and 3.

geometrically representative of actual geophysical contour maps; and insofar as this is true the results will be applicable to any particular contour map.

SECOND DERIVATIVE MAPS

If the values $G(x, y)$ which are contoured on the original map are from a gravimeter or vertical magnetometer survey, they represent a harmonic function on a plane for which the third coordinate, z, is constant. They therefore satisfy Laplace's equation, which may be written in three dimensions as follows:

$$\frac{\partial^2 G}{\partial z^2} = -\left(\frac{\partial^2 G}{\partial x^2} + \frac{\partial^2 G}{\partial y^2}\right). \tag{37}$$

The term on the left side is the second derivative of G in the vertical direction, and the terms on the right are second horizontal derivatives in the x and y directions. If the data are sufficiently accurate, and if the control is close enough, the two horizontal derivatives can be measured directly on the contour map. Equation (37) then provides a means for calculating the vertical second derivative. The utility of this derivative as an aid in the interpretation of gravity and magnetic data has been discussed in a number of papers published in recent years. (Elkins, 1951; Peters, 1949; Henderson and Zietz, 1949).

By referring to Figure 13, we can write down, from simple geometrical considerations, approximate expressions for the two horizontal derivatives $\partial^2 G/\partial x^2$

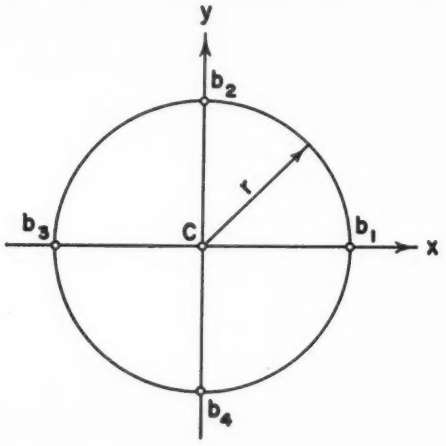


FIG. 13. Diagram used for deriving, geometrically, expressions for second derivatives.

and $\partial^2 G/\partial y^2$. In this figure b_1, b_2, b_3, and b_4 are four points on the original contour map which lie on the circumference of a small circle of radius r whose center is at C. Let the line segments b_3b_1 and b_4b_2 be parallel to the x and y axes respectively. Then, as an approximation to the second horizontal derivative parallel to the x axis we can write (if we let the point designations represent the field values as well)

$$\frac{\partial^2 G}{\partial x^2} \cong (1/r)\left[(b_1 - C)/r - (C - b_3)/r\right] = (b_1 + b_3 - 2C)/r^2. \qquad (38)$$

Likewise, parallel to the y axis

$$\frac{\partial^2 G}{\partial y^2} \cong (1/r)\left[(b_2 - C)/r - (C - b_4)/r\right] = (b_2 + b_4 - 2C)/r^2 \qquad (39)$$

and hence

$$\frac{\partial^2 G}{\partial z^2} = -\left(\frac{\partial^2 G}{\partial x^2} + \frac{\partial^2 G}{\partial y^2}\right) \cong (4/r^2)\left[C - (b_1 + b_2 + b_3 + b_4)/4\right]. \qquad (40)$$

The quantity inside the bracket on the right side of equation (40) is the value at the central point C minus the average of four values on a circle of radius r. It is, therefore, a residual computational process of a simple type which we have already discussed. In the limit, as the radius of the averaging circle approaches zero, we can write equation (40) as follows:

$$\frac{\partial^2 G}{\partial z^2} = \lim_{r \to 0} (4/r^2)\left[C - (b_1 + b_2 + b_3 + b_4)/4\right]. \qquad (41)$$

In other words, the true mathematical second vertical derivative is, except for the constant factor $4/r^2$, the limiting case of a very simple type of grid computing process which is in common use to produce so-called residual maps (Peters, 1949).

Now if the x and y axes, in Figure 13, are rotated about the point C by a small angle $\pi/2n$, and a new set of values b_5, b_6, b_7, and b_8 are interpolated from the contour map where the new axes intersect the circle of radius r, we can write, as in equation (40), since $\partial^2 G/\partial z^2$ will be invariant,

$$\frac{\partial^2 G}{\partial z^2} \cong (4/r^2)\left[C - (b_5 + b_6 + b_7 + b_8)/4\right]. \qquad (42)$$

If this process is repeated n times and the corresponding n equations of the type of (40) and (42) are added together the result is

$$\frac{\partial^2 G}{\partial z^2} \cong (4/r^2)\{C - [(b_1 + b_2 + b_3 + b_4) + \cdots + (b_{4n-3} + b_{4n-2} + b_{4n-1} + b_{4n})]/4n\}. \qquad (43)$$

If n is made large, the values b_n will be closely and equally spaced around the circumference of the circle and the quantity inside the bracket approaches the true average value on the periphery of the circle. Comparison of equations (40) and (43) shows that the second vertical derivative is approximated either by using four values equally spaced on a small circle, or by using a large number of them. If values could be interpolated, or read, from the original contour map

with absolute accuracy, four would theoretically be sufficient. Such precision, however, is seldom inherent in the data from geophysical surveys. Therefore, eight or ten values, or more, are usually employed in order to give a better average on the circle. As the radius of the circle approaches zero the approximate relationship in equation (43) becomes exact, and we can write

$$\frac{\partial^2 G}{\partial z^2} = \lim_{r \to 0} (4/r^2)[C - \text{average value on circle of radius } r]. \tag{44}$$

On actual maps it is not possible to reduce the radius of the circle indefinitely. The practical limit, for the type of control usually obtained in most surveys, is of the order of one half to one mile. In areas where the anomalies are not too sharp this will often give a close approximation to the second derivative.

When the radius of the circle is finite, or large, the simple computational process discussed here loses its identity as a true second derivative and the resulting contour map is more properly termed a "derived" map or simply a residual map. Regardless of the radius of the circle, however, the procedure always retains its simple physical significance as being a measure of the departure of the value at the central point from its neighborhood average. From the purely geometrical viewpoint this simple interpretation appears to be more meaningful than any significance which can be attached to the mathematical second derivative. The selective characteristics of this type of residual, for circles of any radius, are exemplified by the attenuation curves of Figure 10.

Instead of starting with the geometry of Figure 13 we can analyze the second derivative process by starting with equation (2), which is the general equation for any contour map, and write an expression for the second derivative as follows:

$$\frac{\partial^2 G}{\partial z^2} = -\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right)(1/4\pi^2) \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} T^*G(x, y) e^{i(\omega x + \psi y)} d\omega d\psi. \tag{45}$$

Performing the differentiation under the integral sign gives:

$$\frac{\partial^2 G}{\partial z^2} = (1/4\pi^2) \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} T^*G(x, y)(\omega^2 + \psi^2) e^{i(\omega x + \psi y)} d\omega d\psi. \tag{46}$$

If we let $T^*(\partial^2 G/\partial z^2)$ be the Fourier transform of $\partial^2 G/\partial z^2$ then it follows from equation (46) that

$$T^*\left(\frac{\partial^2 G}{\partial z^2}\right) = (\omega^2 + \psi^2) T^*G(x, y) = F(\omega, \psi) T^*G(x, y) \tag{47}$$

where the attenuation function, $F(\omega, \psi)$, is given by

$$F(\omega, \psi) = \omega^2 + \psi^2. \tag{48}$$

Thus a residual computational process which is characterized by an attenuation

function of the form given by equation (48) will produce a second vertical derivative map.

We refer again to Figure 13 which represents a template for a computational process in which the residual value at the central point C is the original value at that point minus the average of four values on the circumference of the circle of radius r. From equation (23) we find that the attenuation function $F(\omega, \psi)$ for this operation is

$$F(\omega, \psi) = 1 - (1/2)(\cos \omega r + \cos \psi r). \tag{49}$$

By substituting for $\cos \omega r$ and $\cos \psi r$ their series expansions, in terms of powers of r, in equation (49) we get

$$F(\omega, \psi) = r^2(\omega^2 + \psi^2)/4 - r^4(\omega^4 + \psi^4)/2 \cdot 4! + r^6(\omega^6 + \psi^6)/2 \cdot 6! - \cdots . \tag{50}$$

This equation may be written

$$(4/r^2)F(\omega, \psi) = (\omega^2 + \psi^2) - 2r^2(\omega^4 + \psi^4)/4! + 2r^4(\omega^6 + \psi^6)/6! - \cdots . \tag{51}$$

Now if we let $F'(\omega, \psi)$ designate the attenuation function for a modified computing procedure in which the residual value at the central point, C, is $4/r^2$ times the difference between this central value and the average of the four values on the circle of radius r, we have

$$F'(\omega, \psi) = (4/r^2)F(\omega, \psi). \tag{52}$$

Substituting this in equation (51) gives

$$\begin{aligned} F'(\omega, \psi) &= (4/r^2)F(\omega, \psi) \\ &= (\omega^2 + \psi^2) - 2r^2(\omega^4 + \psi^4)/4! + 2r^4(\omega^6 + \psi^6)/6! - \cdots \end{aligned} \tag{53}$$

and in the limit, as r approaches zero, it is evident from equation (53) that

$$\lim_{r \to 0} F'(\omega, \psi) = \omega^2 + \psi^2. \tag{54}$$

By comparing equations (54) and (48) it is seen that this modified residual computation gives the second vertical derivative. That is,

$$\lim_{r \to 0} (4/r^2)[C - (1/4)(b_1 + b_2 + b_3 + b_4)] = \frac{\partial^2 G}{\partial z^2} \cdot \tag{55}$$

Equation (55) is identical with equation (41), which was derived from geometrical considerations.

As already pointed out, it is not possible, on an actual geophysical contour map, to carry out the computations specified by equation (55) on a circle of indefinitely small radius. However, if we plot a curve showing the quantity $(4/r^2)[C-(1/4)(b_1+b_2+b_3+b_4)]$ as a function of r^2 for several circles of increasing radii centered at the point C, and then project this curve back through the

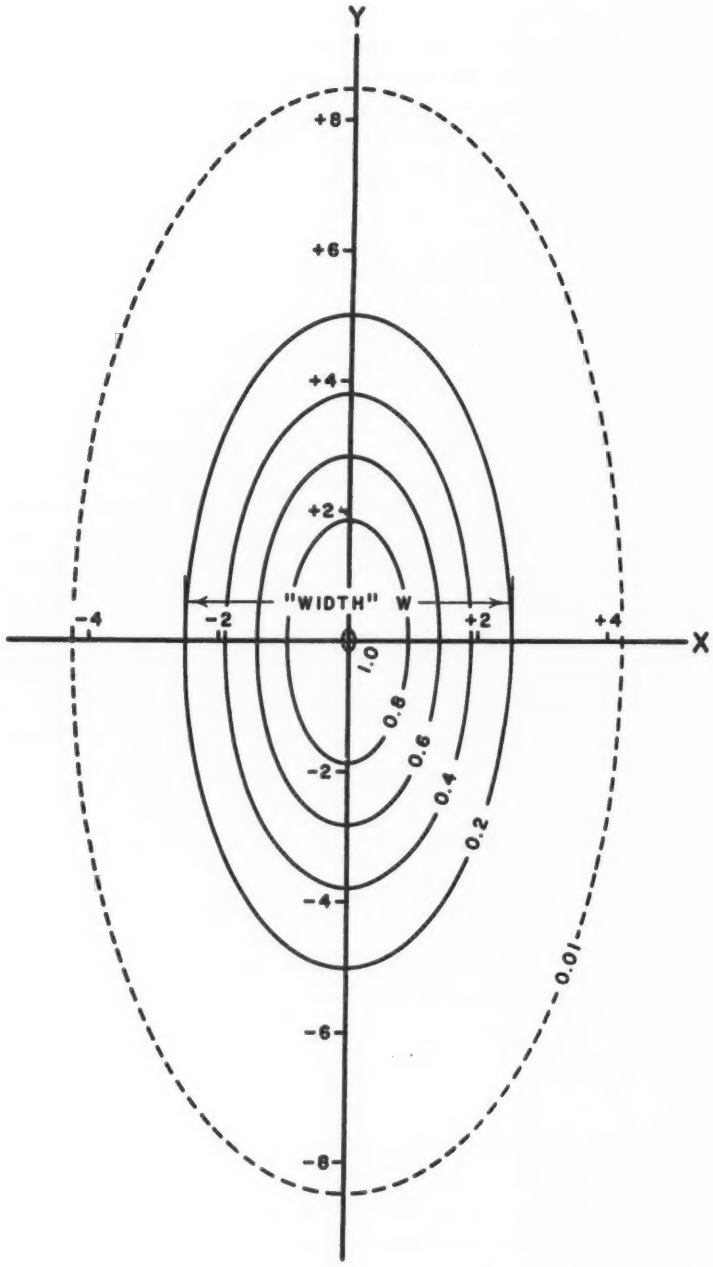


FIG. 14. Contours on single anomaly original map whose equation is $G = e^{-.25(x^2+.25y^2)}$.

axis, $r^2=0$, a good approximation to the value of the second vertical derivative will be obtained.

Moreover, it can readily be shown that if the computational procedure involves the average of a very large number of values on the circle, instead of only four, the limit value of the attenuation function $F'(\omega, \psi)$, for small r, will still have the form of equation (48). This procedure, therefore, will also give the true mathematical second derivative. In other words, if we plot a curve showing the quantity $(4/r^2)\cdot(C$—average value on a circle of radius $r)$ as a function of r^2, and project the curve back through the zero axis, the intercept will be the second derivative. This operation is recognized as the equivalent of the graphical method which has already been described by Peters (1949) and Elkins (1951) for determining second derivatives.

SINGLE ANOMALY MAPS

The attenuation curves we have derived so far are for original maps of a continuous mosaic type, consisting of an infinite repeated pattern of uniform anomalies. It is of interest to compare these curves with those for an original contour map which consists of a single anomaly.

For this purpose we will take a single anomaly of the form given by the following equation:

$$G = e^{-(6.4/W^2)(x^2+y^2/q^2)} \qquad q^2 > 1. \tag{56}$$

This anomaly has its apex at the origin, where its maximum value is equal to one. The contours have the form of ellipses. Since $q^2>1$, the major axes are along the y axis, and the minor axes are along the x axis. The ratio of the major to the minor axis, i.e., the ratio of the length to the width of the anomaly, is q. W is the length of the minor axis of the elliptical contour corresponding to $G=0.2$. Figure 14 is a contour map illustrating such an anomaly for which the parameters are $W=5$ and $q=2$.

This type of anomaly is symmetrical with respect to both the x and the y axes. A residual map prepared from it by the use of a symmetrical template will also be symmetrical with respect to both axes.

If we take the residual value at the origin as a measure of the magnitude, or relief, of the residual anomaly, then by reference to Figure 8 it will be seen that this central value, G_0', for a residual process consisting merely of the average of eight values on a circle of radius r, is given by the following equation:

$$G_0' = (1/4)e^{-6.4(r/W)^2} + (1/4)e^{-6.4(r/qW)^2} + (1/2)e^{-3.2(r/W)^2(1+1/q^2)}. \tag{57}$$

In Figure 15, G_0' is plotted as a function of $W/2r$ for $q=1$, 2, and ∞. These attenuation curves show how the normalized central value of the residual anomaly varies with the relative width and the shape of the original anomaly. The "width" W of the original anomaly is defined as the minor axis of the elliptical contour corresponding to a value of G equal to one fifth the maximum value.

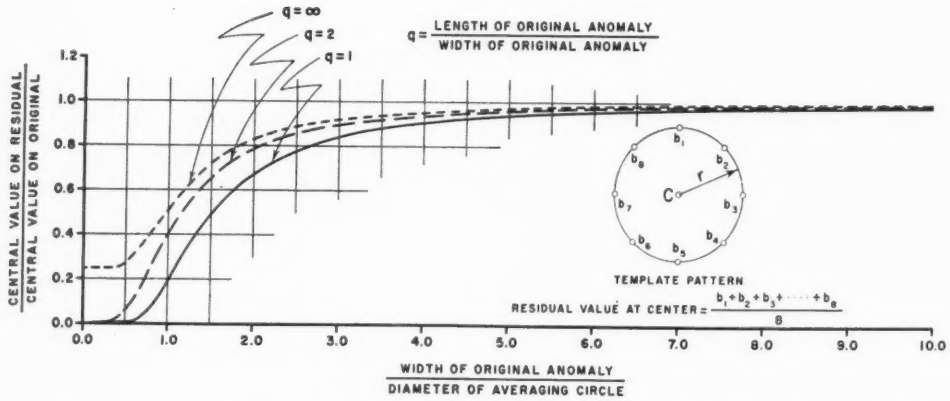


FIG. 15. Attenuation curves for a residual map prepared by averaging eight values on a circle of radius r on the original map, when the original map is a single anomaly of the general type illustrated by Figure 14.

These curves are very similar to those of Figure 9, for a mosaic type of original map, except that in the present case, due to the nonrepetitive character of the original anomaly, the resonant oscillations near the origin are not present. It is evident that the main characteristic of this type of residual is the rapid attenuation of the small anomalies.

If the residual is constructed by subtracting the average of eight values on a circle of radius r from the value at the center of the circle, then the central residual value is given by

$$G_0'' = 1 - (1/4)e^{-6.4(r/W)^2} - (1/4)e^{-6.4(r/qW)^2} - (1/2)e^{-3.2(r/W)^2(1+1/q^2)}. \quad (58)$$

In this case the residual anomaly will not be positive everywhere but will consist of a positive central anomaly surrounded by negative values. As before, the central value at the origin will be taken as the geometrical parameter characterizing

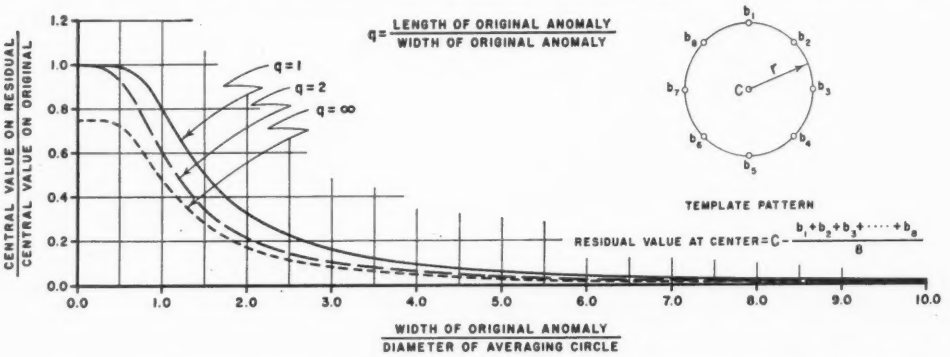


FIG. 16. Attenuation curves for a residual map prepared by subtracting the average of eight values on a circle of radius r, on the original map, from the value at the center, when the original map is a single anomaly of the general type illustrated by Figure 14.

the magnitude of the residual. The attenuation curves corresponding to equation (58), for values of q equal to 1, 2, and ∞, are plotted in Figure 16. Again they are very similar to the curves of Figure 10, for the mosaic type original map, except that the repeated maxima and minima near the origin are absent. They show that this type of residual strongly attenuates the larger anomalies and retains the smaller ones.

For a residual prepared by subtracting the average of eight values on a circle of radius $3r$ from the average of eight values on a circle of radius r, the central value is given by

$$G_0''' = (1/4)e^{-6.4(r/W)^2} + (1/4)e^{-6.4(r/qW)^2} + (1/2)e^{-3.2(r/W)^2(1+1/q^2)} - (1/4)e^{-57.6(r/W)^2} - (1/4)e^{-57.6(r/qW)^2} - (1/2)e^{-28.8(r/W)^2(1+1/q^2)}. \quad (59)$$

The corresponding attenuation curves for $q=1$, 2, and ∞ are plotted in Figure 17. They are similar to those in Figure 11, and indicate that this residual computing procedure strongly attenuates both the large and the small anomalies and retains, with relatively slight attenuation, those in an intermediate range where the width of the anomaly is approximately equal to the mean diameter of the two averaging circles.

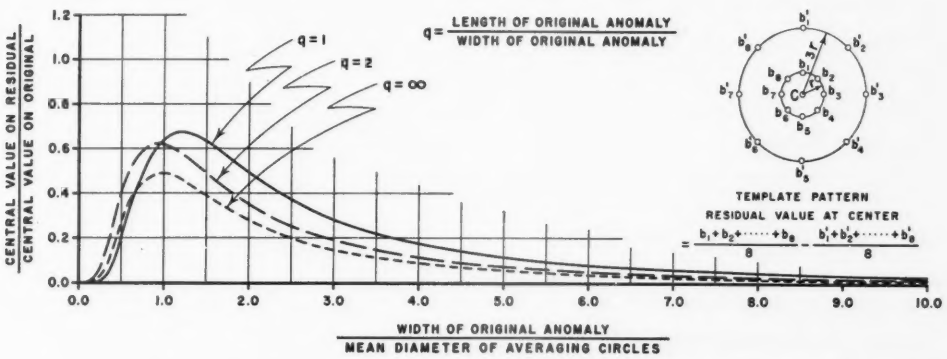


FIG. 17. Attenuation curves for a residual map prepared by subtracting the average of eight values on a circle of radius $3r$, on the original map, from the average of eight values on a circle of radius r, when the original map is a single anomaly of the general type illustrated by Figure 14.

DISCUSSION

It would hardly be possible to prepare a family of curves, or to present information in simple graphical form, which would describe completely the selective characteristics or the filtering properties of the various kinds of residual processes when they operate upon an original contour map of perfectly arbitrary type. The attenuation curves given here do, however, give such information for contour maps which may be considered to be representative of two oppositely extreme types. At one extreme is the single anomaly of simple regular form, and at the opposite extreme is the uniform mosaic of simple anomalies. Actual maps

encountered in practice usually lie somewhere between these two categories. The attenuation curves for both types, as already shown, are remarkably similar. Therefore, it is believed that they can be used as an aid in designing residual templates to have the desired selective effect on the particular map at hand. In the range in which they are most useful, these curves for typical templates are not sharp filter curves, consequently, the relative discrimination to be expected between different anomalies is definitely limited.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the numerous valuable suggestions received from R. A. Peterson of United Geophysical Company, Inc., as well as the help of Helenita Officer, who carried through the computations and prepared the preliminary drawings, and of R. L. Duke for the final drafting.

REFERENCES

Agocs, W. B., 1951, Least squares residual anomaly determination: Geophysics, v. 16, p. 686–696.

Elkins, T. A., 1951, The second derivative method of gravity interpretation: Geophysics, v. 16, p. 29–50.

Griffin, W. R., 1949, Residual gravity in theory and practice: Geophysics, v. 14, p. 39–56.

Henderson, R. G. and Zietz, I., 1949, The computation of second vertical derivatives of geomagnetic fields: Geophysics, v. 14, p. 508–516.

Peters, L. J., 1949, The direct approach to magnetic interpretation and its practical application: Geophysics, v. 14, p. 290–320.

A NOTE ON DOWNWARD CONTINUATION OF GRAVITY*

CÉSAR A. TREJO†

ABSTRACT

Comparing calculated and exact values in an ideal example, it is shown that Peters' proposed method of downward continuation of gravity is far less suitable than a combination of Peters' procedure for upward continuation and a finite differences method for downward continuation. It is shown also how Peters' method can be substantially improved by considering only the closest values in the downward step of a continuation process.

Several methods have been developed to solve the important problem of calculating the gravity relief at a given depth from a gravity map at the surface. Peters (1949) has developed a very practical procedure for the magnetic interpretation which is easily adaptable to gravity. It consists of two successive steps:

1. The field is continued upwards up to the height $z=-h$ (h being a side of the grid of observations and z being vertical downwards) by means of the relation (derived on page 295 of Peters' paper)

$$g(x,\ y,\ -h) = \int_0^\infty \frac{\bar{g}(r)\,hrdr}{(h^2+r^2)^{3/2}}, \tag{1}$$

where $\bar{g}(r)=(2\pi)^{-1}\int_0^{2\pi} g(r,\theta)d\theta$ is the mean value of g over the circumference of a circle having a radius r at $z=0$. The integral of equation (1) is approximated by a sum using the value $g(x, y, 0)$ at the station, and values of $\bar{g}(r_i)$ on the circumferences of nine circles with centers at the station. Each $\bar{g}(r_i)$ is approximated by taking the average of gravity values on stations forming a regular or nearly regular polygon (Figure 1).

2. Once the gravity map at $z=0$ and at the height $z=-h$ is known, the Taylor expansion

$$g(x,\ y,\ h) = g(x,\ y,\ 0) + \frac{h}{1!}\frac{\partial}{\partial z}g(x,\ y,\ 0) + \frac{h^2}{2!}\frac{\partial^2}{\partial z^2}g(x,\ y,\ 0) + \cdots, \tag{2}$$

when added to the corresponding expansion obtained by replacing h with $-h$, gives (Peters, 1949, pp. 299–301) by use of Laplace's equation and polar coordinates, the following approximate formula for the relief at the depth $z=h$:

$$g(x,\ y,\ h) \simeq 2\left[b_0 - 2b_2h^2 + \frac{8}{3}b_4h^4\right] - g(x,\ y,\ -h). \tag{3}$$

The coefficients b_0, b_2, b_4 are calculated by least squares using the averages $\bar{g}(r_i)$, which can be expressed in the approximate form $\bar{g}(r)\simeq b_0+b_2r^2+b_4r^4$.

* Manuscript received by the Editor July 13, 1953.

† Argentine Government Owned Oil Fields, Buenos Aires, Argentina. The author wishes to express his indebtedness to Rodolfo Martin for his valuable suggestions.

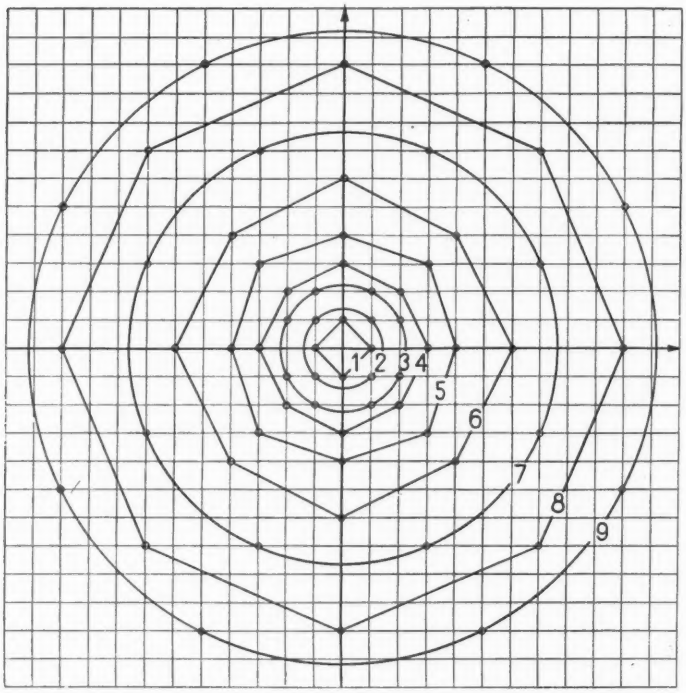


FIG. 1. Arrangement of gravity stations on circles and polygons for application of Peters' method.

The degree of accuracy of the method is not considered in Peters' paper. Disregarding here the problem of looking for an upper limit of the resulting errors, we can get an idea of their magnitude by calculating the errors in a simple ideal case. If we consider a sphere centered at (0, 0, $2h$), i.e. at the depth $z=2h$, the gravity map at the depth $z=h$ may be computed exactly, and compared with the one obtained by continuation from $z=0$. The values obtained using the coefficients of Peters' Table III (p. 302 of his paper), are in complete disagreement with the exact ones (see Table II below, columns 2 and 3).

Bullard and Cooper (1948) use, for the two-dimensional case, a method of finite differences which, as they point out, can be extended to the three-dimensional case. By this extension g can be determined at any point by averaging the values of the six nearest neighbors (at the distance h) in a cubical grid. Applying the method, for example, to the grid shown in Figure 2, we have

$$g(0, 0, h) = 6g(0, 0, 0) - g(h, 0, 0) - g(-h, 0, 0) - g(0, h, 0) - g(0, -h, 0) - g(0, 0, -h). \quad (4)$$

This relation gives the value of g at the depth h, in terms of measured values of g at the surface ($z=0$), and values of g at the height $-h$, calculated by Peters' method of upward continuation.

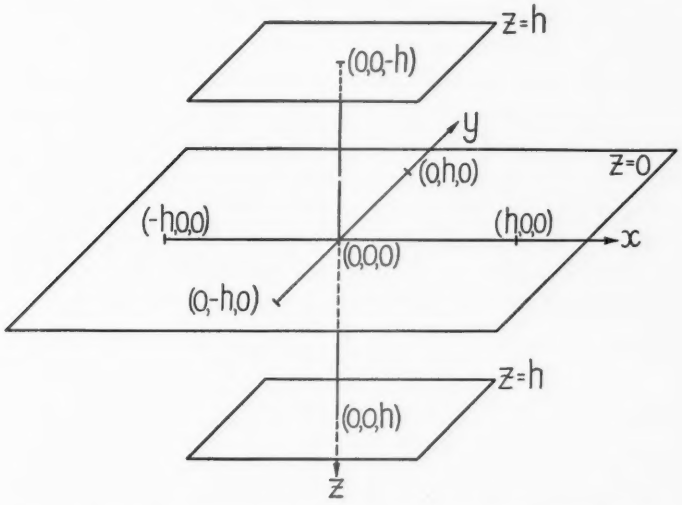


FIG. 2. Three-dimensional grid to illustrate method of finite differences.

Table I gives the coefficients not for the averages $\bar{g}(r_i)$ but for the *sums* $\sum_i$ on the Peters' polygons of Figure 1. These are obtained when the method of finite differences is applied along with Peters' upward continuation method.

TABLE I

COEFFICIENTS OF THE SUMS ON PETERS' POLYGONS FOR DIRECT CALCULATION OF DOWNWARD CONTINUATION, USING THE COMBINED METHOD

i	a_i	i	a_i
0	5.85355	5	−0.00971
1	−1.05283	6	−0.00659
2	−0.03736	7	−0.00431
3	−0.01581	8	+0.00257
4	−0.01078	9	−0.01182

If the gravity map is calculated at $z=h$, using this table, for the case of the sphere (fourth column of Table II below), a much better agreement with the exact values is obtained.

The comparison shows the failure of Peters' method and the efficiency of the one combining the procedure of Peters with finite differences. The combined method is also very readily applicable using the coefficients of Table I. In contrast, the method proposed by Bullard and Cooper, which begins with a downward continuation by an analytical procedure is not suited for application to a grid of squares (see Bullard and Cooper, 1948, p. 335 and Table 3, p. 339).[1]

[1] On the other hand, the analytical method of Bullard and Cooper supposes a smoothing of the observations taking weighed means with a weighting function *everywhere positive*, and it is known this is not convenient as a smoothing method. For the smoothing problem see, for instance. Whittaker and Robinson (1946, Chapter XI).

Peters' method fails due to the fact that b_0, b_2, b_4 were calculated on the basis of *all* the polygons; therefore, values of r which are too great are employed in determining $\bar{g}(r)$. This is not suitable for evaluating the polynomial $y=b_0+b_2r^2+b_4r^4$ which, being made up from the first terms of Maclaurin's expansion of $\bar{g}(r)$, is represented by the osculating fourth degree parabola to the curve $y=\bar{g}(r)$ at the point $r=0$. Therefore, the approximation to $\bar{g}(r)$ is *locally* valid (i.e. in the neighborhood of $r=0$), but not everywhere within an interval (as would be the case, for instance, with an interpolating polynomial). This is shown by calculating b_0, b_2, b_4 with a smaller number of polygons (using only the inner ones), for then the results are sensibly better (see columns 5 and 6 of Table II).

TABLE II

COMPARISON OF EXACT AND APPROXIMATE VALUES OF GRAVITY FROM A SPHERE
(Center of sphere at depth $2h$)

Coordinates[a]	Exact values at depth $z=h=1$[b]	Values with Peters' coeff.[c]	Values with coeff. of Table I[c]	With 6 eq.[c]	With 4 eq.[c]
0;0	500.00	113.51	336.99	146.68	358.75
1;0	176.78	94.69	184.44	118.74	197.21
1;1	96.22	81.75	114.32	99.20	107.75
2;0	44.72	61.53	48.80	69.17	52.99
2;1	34.01	55.57	38.23	60.25	31.94
2;2	18.51	40.70	20.02	38.32	13.17
3;0	15.81	35.46	15.03	34.44	16.88
3;1	13.70	32.42	13.45	27.50	13.79
3;2	9.54	24.58	9.64	17.29	8.19
3;3	6.04	15.24	5.70	5.83	4.91

[a] Orthogonal cartesian coordinates (x, y) in a plane $z=$const., with origin in the vertical projection of the center of the sphere, and in units of h. The values of g on all the points having whole-number coordinates in the square $-3\leqq x\leqq 3$; $-3\leqq y\leqq 3$, are obtained from the values on the indicated points by symmetry.

[b] Conventional units are used, such that the constant of gravitation becomes $k=1$. In the plane of depth $z=h=1$ is $g=(m/d^2)(1/d)=m(x^2+y^2+1)^{-3/2}$, where d, the distance of each point to the center of the sphere, is $(x^2+y^2+1)^{1/2}$. For convenience we assume that $m=500$.

[c] Obtained by superimposing Peters' polygons (Figure 1) upon the gravity map at the surface $z=0$. This map is calculated [compare note [b]] with $g=(m/d^2)(2/d)=2m(x^2+y^2+4)^{-3/2}$.

The result obtained by using the least squares method with only four condition equations (from values at the station and on the three closest polygons) is comparable with that obtained by finite differences. Nevertheless the sum of relative errors is still greater (1.51 against 0.99).

Although the ideal case of a sphere would be inadequate to indicate the accuracy of either of the methods, it is sufficient to establish, *by comparison*, the advantage of the method here developed.

By applying the method of least squares with all the polygons considered by Peters, the normal equations for the coefficients b_0, b_2, b_4 are:

$$\left.\begin{array}{rrrrrrrrr} 9 & b_0 + & 224.5 & b_2 + & 14,712.25 & b_4 = g_0 & + \bar{g}(r_1) + \cdots \\ 224.5 & b_0 + & 14,712.25 & b_2 + & a\cdot 10^6 & b_4 = \bar{g}(r_1) & + 2\bar{g}(r_2) + \cdots \\ 14,712.25 & b_0 + & a\cdot 10^6 & b_2 + & b\cdot 10^8 & b_4 = \bar{g}(r_1) & + 4\bar{g}(r_2) + \cdots \end{array}\right\} \quad (5)$$

where $a\cdot 10^6$, $b\cdot 10^8$ stand for numbers of the order of 10^6 and 10^8 respectively. Therefore the solution given by Peters (1949, p. 301) is seen to be inadequate, because a difference of one unit in the last figure of the given values of the coefficients of $\bar{g}(r_i)$ (10^{-4} in b_0 and b_2, 10^{-5} in b_4), when substitution is made in the previous equations, gives differences of the orders 10^{-1}, 10^1, and 10^3 respectively.

REFERENCES

Bullard, E. C. and Cooper, R. I. B., 1948, The determination of the masses necessary to produce a given gravitational field: Proc. Royal Soc. of London, v. 194, p. 332–347.

Peters, L. J., 1949, The direct approach to magnetic interpretation and its practical application: Geophysics, v. 14, p. 290–319.

Whittaker, E. and Robinson, G., 1946, The calculus of observations: London and Glasgow, Blackie and Son, Ltd.

THE CORRELATION BETWEEN PRE-CAMBRIAN ROCK DENSITIES AND BOUGUER GRAVITY ANOMALIES NEAR PARRY SOUND, ONTARIO*

C. H. G. OLDHAM†

ABSTRACT

A gravity survey and a survey of rock densities have been carried out over an area of two thousand square miles near Parry Sound. A closed positive Bouguer gravity anomaly of thirty milligals was delineated, and a considerable variation was found to exist in the densities of pre-Cambrian gneisses. In most previous interpretations of gravity over the Canadian Shield the gneisses have been assumed to possess a uniform density and anomalies have been attributed to changes in the thickness of horizontal crustal layers. In this paper it is shown that the Parry Sound anomaly can be explained in terms of structures within the crust taking the form of projections downward of the density variations found at the surface. The postulated structure is a nearly circular basin of dense gneisses. The shape is reasonable and agrees with such geological evidence as is available.

INTRODUCTION

During the past few years gravity observations have been made over large areas of the pre-Cambrian Shield. Most of this work has been done by the Gravity Division of the Dominion Observatory in Ottawa, but some measurements have been made in southern Ontario by members of the Department of Physics at the University of Toronto.

In the interpretations of this work which have so far been published (Garland, 1950 and 1951; Fitzpatrick, 1950), corrections were made for surface density contrasts between such rocks as Keewatin greenstones and pre-Cambrian gneisses; the latter were, however, assumed to possess a uniform density. Other gravity anomalies covering larger areas of the Canadian Shield have been explained by Innes (1952), Garland (1950), Uffen (1950), and Prendergast (1951), who have postulated variations in the thickness of the crustal layers as indicated by seismology. These authors gave this explanation in the absence of detailed density determinations.

Because of this scarcity of combined density and gravity surveys over basement rocks and because of the present uncertainty as to whether the crust is layered, a test survey was made over a positive gravity anomaly known to occur in the vicinity of Parry Sound. This was done to investigate the possibility that this particular anomaly might be explained in terms of density variations within the gneisses, rather than by invoking crustal layering and warping.

GEOLOGICAL DATA

The region under investigation is a level area of about two thousand square

* Manuscript received by the Editor, May 26, 1953. The material in this paper is the subject matter of an M.A. thesis submitted by the author to The University of Toronto.

† University of Toronto, Toronto, Ontario, Canada.

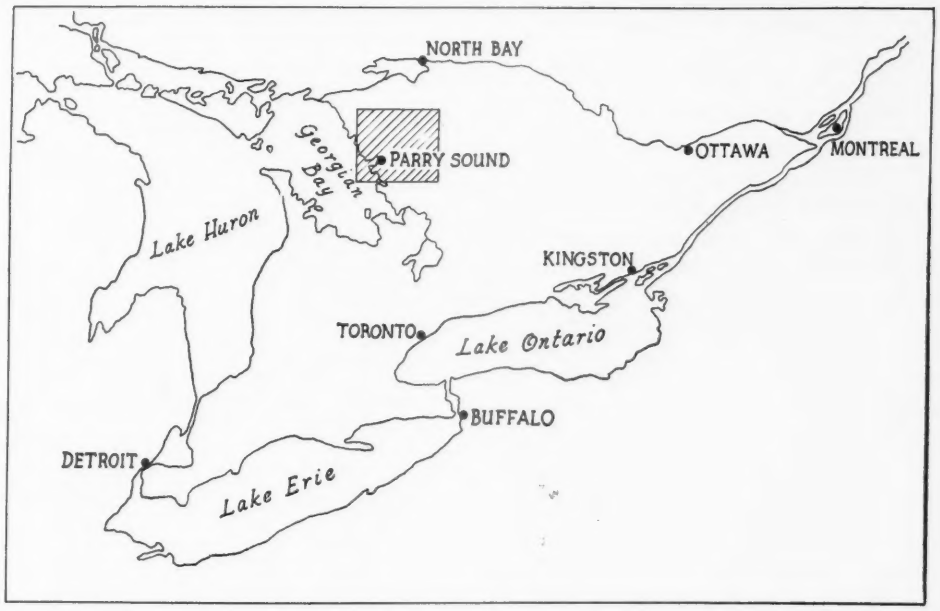


FIG. 1. Map showing the position of the Parry Sound area.

miles, and lies within the Grenville Province of the Shield. Figure 1 indicates the approximate geographical location.

The principal geological data available are in a report and map compiled by Satterly (1942). Since his observations were made only along the roads and at mineral deposits, the map is of a reconnaissance nature. A simplified sketch of this map is reproduced in Figure 2. Satterly distinguished three main rock types: hornblende gneiss, biotite gneiss and hybrid granite gneiss, although he points out that almost every gradation between the three occurs. The hornblende and biotite gneisses outcrop mainly in the central five hundred square miles of his area. The detailed structure is very complex and the rocks are highly metamorphosed.

By interpretation of aerial photographs, Angela Burlinson has plotted a foliation pattern for large areas of the Grenville Province. This work, which was carried out in this laboratory, has not yet been published, but Figure 4 represents the results in the Parry Sound area, published with her kind permission.

GEOPHYSICAL DATA

Gravity

The hundred gravity stations in the area were established in the summer and fall of 1951 by J. T. Wilson, G. D. Garland, and the author, all from the University of Toronto. A North American type gravimeter was used, having a scale constant of .0966 milligals per scale division. Primary base stations were estab-

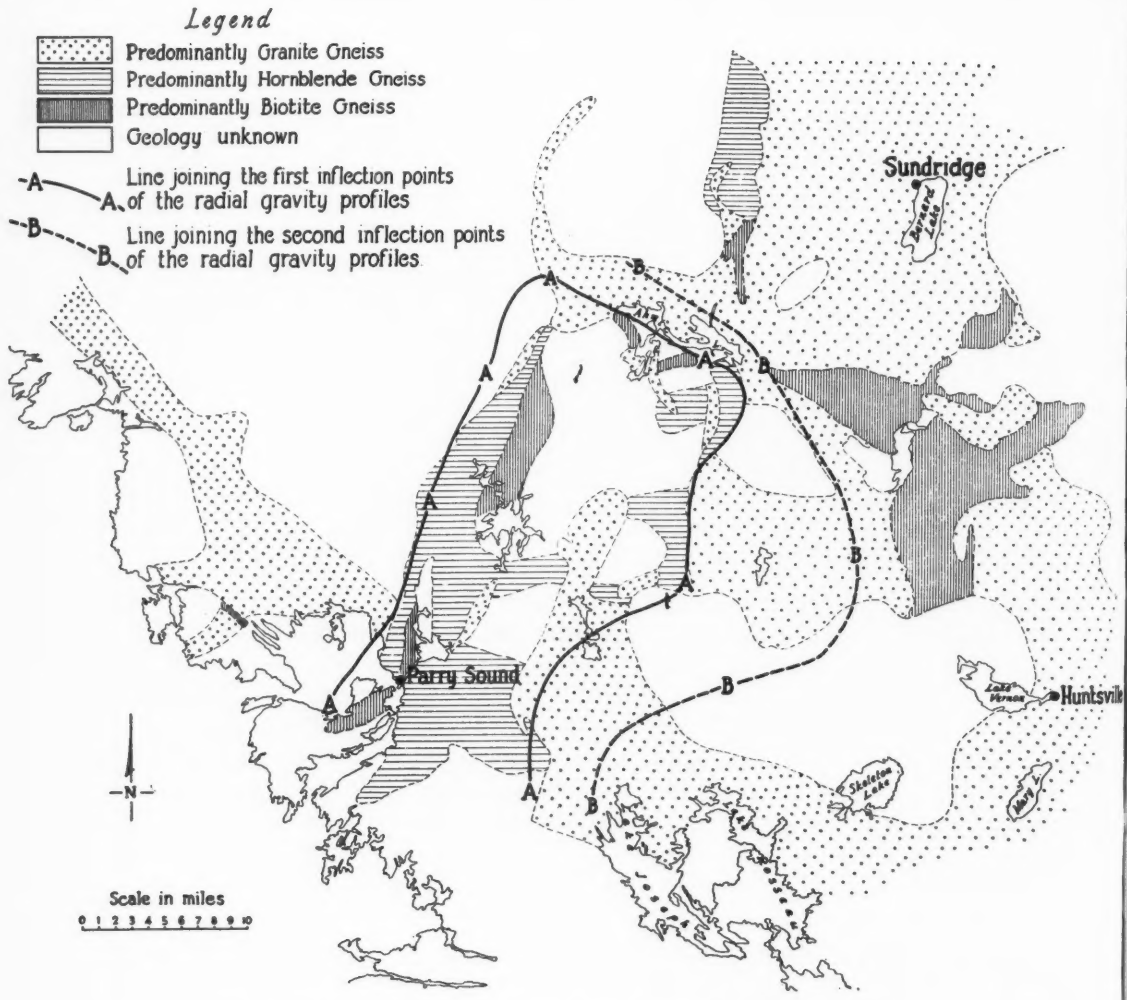

Legend
Predominantly Granite Gneiss
Predominantly Hornblende Gneiss
Predominantly Biotite Gneiss
Geology unknown
Line joining the first inflection points of the radial gravity profiles
Line joining the second inflection points of the radial gravity profiles
Sundridge
Parry Sound
Huntsville
Scale in miles
0 1 2 3 4 5 6 7 8 9 10

FIG. 2. Geological sketch map of the Parry Sound area (after J. Satterly).

lished at Parry Sound, Huntsville, and Orillia, the latter being looped with Toronto, which had previously been tied with the national base of the Dominion Observatory at Ottawa. The observed values were corrected for drift, variations in latitude, elevation, and the effect due to the mass of rock between the gravity station and sea level. The resultant Bouguer anomalies were then plotted and contoured as shown in Figure 3. Where possible the gravity stations were established at points where the elevation was known from maps of the National Topographic Series; elsewhere the elevations were determined with an altimeter relative to nearby bench marks. These elevations are considered to have a probable error of about plus or minus five feet, and these limits, when using a density

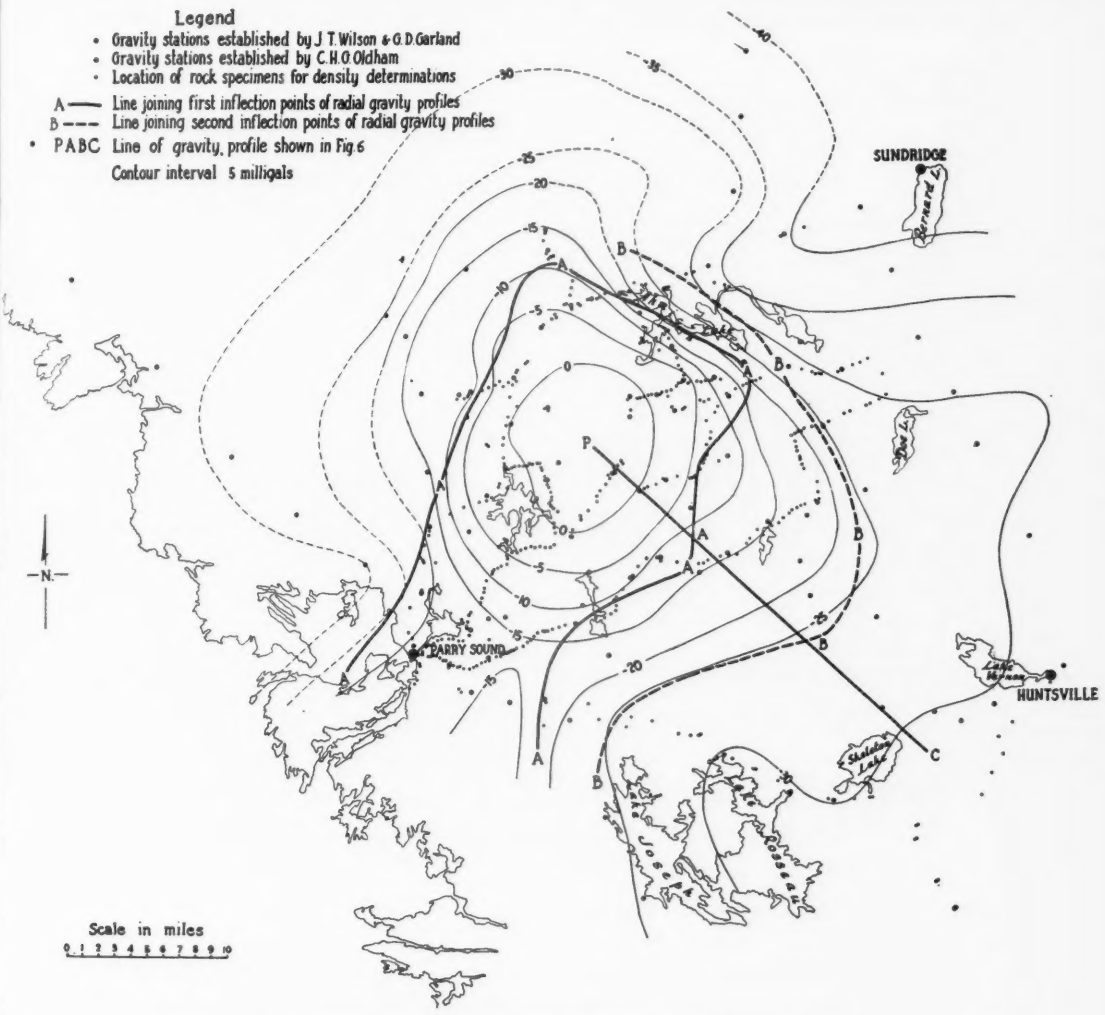

Legend
Gravity stations established by J. T. Wilson & G. D. Garland
Gravity stations established by C. H. O. Oldham
Location of rock specimens for density determinations
A —— Line joining first inflection points of radial gravity profiles
B --- Line joining second inflection points of radial gravity profiles
PABC Line of gravity profile shown in Fig. 6
Contour interval 5 milligals
SUNDRIDGE
PARRY SOUND
HUNTSVILLE
Lake Rosseau
Skeleton Lake
N.
Scale in miles
0 1 2 3 4 5 6 7 8 9 10

FIG. 3. Bouguer anomaly contour map of the Parry Sound area.

of 2.67 in the Bouguer correction, introduce a probable error of about plus or minus 0.3 milligals in the combined Bouguer and free air correction factor.

Rock Densities

The rock specimens were obtained by driving along roads and lumber trails in the area and selecting representative samples from road-side exposures. Specimens were collected at intervals of about one-quarter mile, care being taken to ensure that the samples were unweathered and representative of the outcrops. In this way, and by taking a large number of specimens, it was hoped to obtain a representative selection of the rocks occurring in this area, although it was

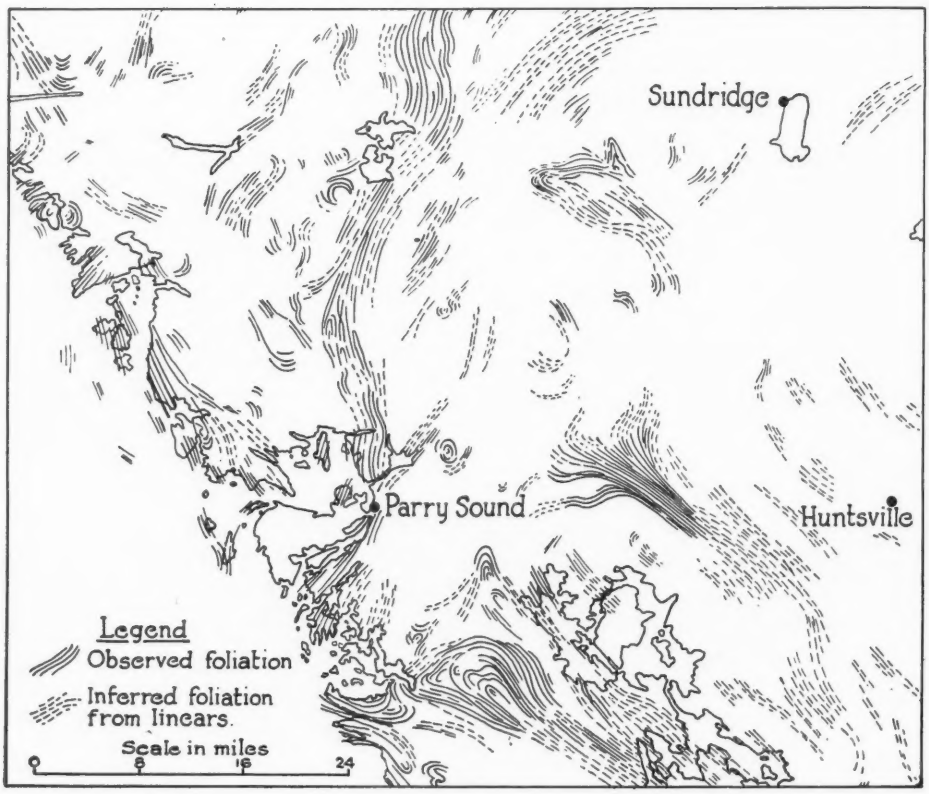


FIG. 4. Foliation pattern of the Parry Sound area obtained from the interpretation of aerial photographs by Angela Burlinson.

realized that the samples would contain a preponderance of the less easily eroded rocks.

The density of each sample was determined using the buoyancy method, no special precautions being necessary since all the specimens were impervious. The results of these density determinations showed there to be a considerable variation in the densities of the gneisses, the more basic types being denser than the granitic types. The locations where the samples were obtained for which density determinations were made are shown in Figure 3.

INTERPRETATION

General

A comparison of Figures 2 and 3 reveals how closely the center of the gravity anomaly corresponds with the main outcrop of the basic gneisses. The extension of the hornblende gneisses to the southwest is closely followed by the gravity contours, and the area of biotite gneiss to the east of the main outcrop is reflected by the deflection of the −30 milligal contour to the east. These observations,

coupled with the fact that the areas mapped as basic gneisses were noted to contain many more high density samples than those mapped as granite gneisses, suggested that the anomaly might be due to simple downward extensions of the same rocks that occur at the surface. This was investigated.

Determination of Average Densities

A profile of the gravitational force across the vertical edge of an horizontal slab of rock having a density different from that of its surroundings would show an inflection point immediately above the edge. If this edge was dipping, the inflection point would be displaced slightly to one side, but would, nevertheless, give an approximate indication of the location of the edge. This principle was used to delineate the main area of the body causing the anomaly. Profiles of values of gravity were drawn radially out from the center of the anomaly in eleven different directions, as shown in Figure 5. Those profiles which crossed an accurately known geological boundary between the basic gneisses and the granite gneisses had the inflection points very close to the boundary. This constituted a further justification for assuming that the basic gneisses were the cause of the

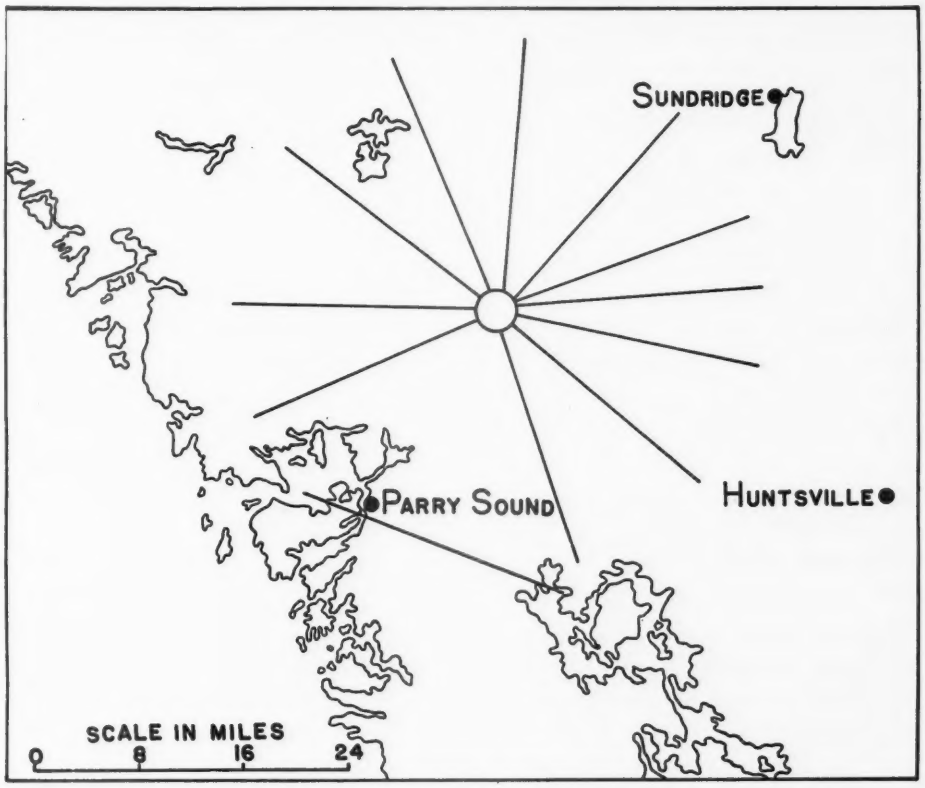


FIG. 5. Map showing the location of the gravity profiles used to delineate the density zones.

anomaly. The inflection points on the other profiles were assumed to indicate where the boundary might be expected in the unmapped areas, and for the purpose of this interpretation the line joining the inflection points of the various profiles was assumed to be approximately the required geological boundary.

Where the gravity control was sufficiently good the profiles revealed a second inflection point, at a distance from the center about twice that of the first one. These inflection points were also joined, the boundaries being indicated in both Figures 2 and 3. Average densities were found for each of the three zones (inner, intermediate, and outer), and the results are listed in Table I.

TABLE I

Zone	Number of Specimens	Average Density	Standard Deviation	Probable Error
Inner	278	2.85 gms/cc	0.147 gms/cc	0.006 gms/cc
Intermediate	104	2.74 gms/cc	0.120 gms/cc	0.008 gms/cc
Outer	43	2.69 gms/cc	0.059 gms/cc	0.006 gms/cc

It has been shown (Weatherburn, 1949) that if there exists n_1 and n_2 members of two samples respectively, then the difference in their means is significant and not due to fluctuations of sampling if the observed difference in their means is greater than three times the square root of the sums of the squares of the standard errors of the two means; i.e. for significance, δ must be $> 3\epsilon$,
where

$$\epsilon^2 = \frac{{\sigma_1}^2}{{n_1}^2} + \frac{{\sigma_2}^2}{{n_2}^2},$$

σ_1 and σ_2 being the respective standard deviations, and where δ is the observed difference in the means. This method was applied to test the significance of the three density zones and the results are listed in Table II.

TABLE II

Zone Contrast	3ϵ	Observed difference in means
Inner and Outer	.039	.16
Intermediate and Outer	.045	.05
Inner and Intermediate	.074	.11

From these results, it appears that there is statistical confirmation of the existence of the three zones suggested by the gravity profiles.

Much of the northwestern section of the area was inaccessible by road and consequently very few samples for density determinations were collected there. The gravity stations which do exist in this sector suggest that the contours may be extended with their approximately circular shape, and for the purpose of the

interpretation, the density zones, as determined above, are also assumed to be continued in this region.

Quantitative Interpretation

The interpretation of the anomaly followed the indirect approach of assuming certain basic facts about the anomaly-causing body such as the shape, size, and density, calculating its gravitational effect, and then varying the assumed parameters until the observed and calculated curves agreed. In the present case the dimensions and the density of the body were known at the surface; it therefore remained to estimate the shape at depth.

The first stage in this interpretation problem was to remove regional effects. This was done using the gravity map of southeastern Ontario compiled by Prendergast (1951). Reference to this map revealed that the Parry Sound anomaly was a "local" high on an approximately northeast to southwest trending gravity high which extends from the North Bay area to Michigan.

A profile, shown in Figure 6, was drawn at right angles to this regional high passing through the center of the Parry Sound anomaly. From this it was possible to estimate the regional effect; the solid curve of Figure 7 is the gravity profile extending from the center of the anomaly to the southeast, with this regional effect removed.

The approximately circular shape of the isogals in Figure 3 suggested that

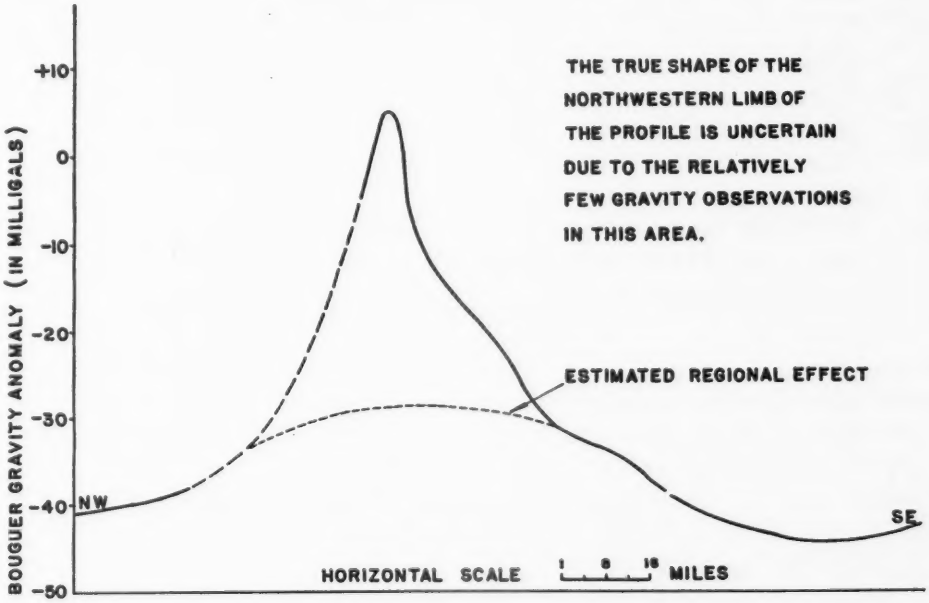


FIG. 6. Northwest to southeast profile across the center of the Parry Sound anomaly illustrating the regional effect.

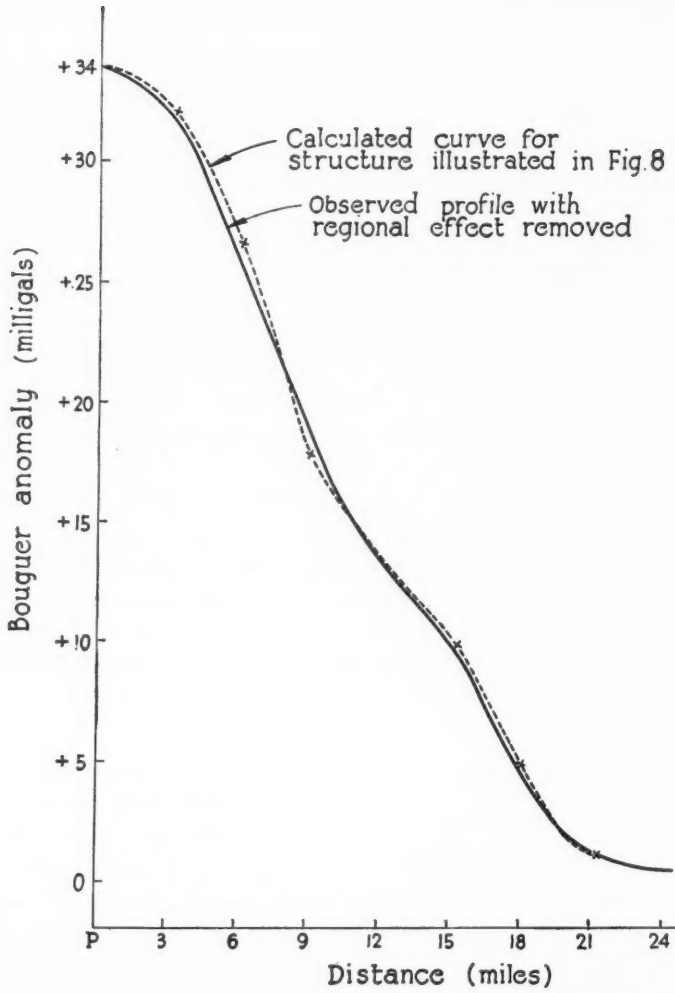


FIG. 7. Observed and computed gravity profiles along line PC of Figure 3.

the anomaly-causing body itself would have a circular cross-section. Hence, as a first approximation, two coaxial cylinders were postulated. An inner cylinder with a density of 2.85 gm/cc was taken to have a radius of 8.5 miles, as given by the distance from the center to the first inflection point of the selected gravity profile. An outer cylinder was taken with a radius of 17 miles, given by the distance from the center to the second inflection point. The density of the rock between the two coaxial cylinders was 2.74 gm/cc. The country rock outside the cylinders was found to have a density of 2.69 gm/cc as shown by the averages in Table I.

The gravitational effects of such a structure, at points along a radial profile,

were computed using the solid-angle technique described by Nettleton (1942). The vertical component of gravity at any point due to a thin lamina may be shown to be proportional to the solid angle subtended by the median plane of the lamina at that point. For this relation to hold, the thickness of the lamina shall be less than about half its mean depth. For a further discussion on the theory and limitations of this method the reader is referred to Nettleton (1942) and Pelini (1930).

In the present investigation the cylinders were divided into a number of laminae, and the total gravity effect at any point was simply the sum of the individual effects due to each lamina.

Difficulties were encountered in computing the effects due to the surface lamina since the depth to its median plane is half, rather than over twice, its thickness. It is possible to compute the gravitational attraction at points over the center, and over the edge of a circular cylinder using exact mathematical formulas. This was done for the uppermost lamina. It was found that the results so obtained differed at the most by only 3.2% from those obtained using the solid-angle method for the same points. Since the surface lamina never contributed more than about a quarter of the total effect at any point, it was considered sufficiently accurate to use the solid angle method for all laminae.

It was found that the gravity values computed for the double cylindrical structure were incapable of explaining the relatively steep gradients observed near the peak of the anomaly. A body which tapered with depth was required.

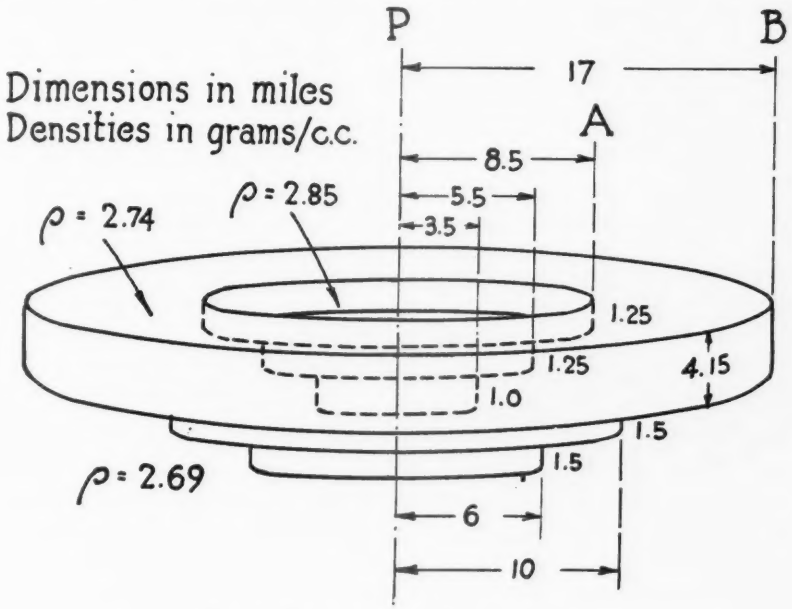


FIG. 8. Sketch of the proposed structure.

The effects due to a series of laminae whose radii decreased with depth were now computed. By varying the thickness and radii of the successive discs a structure was eventually obtained which satisfactorily explained the observed anomaly. The computed effect of this body is shown by the dotted curve in Figure 7. A sketch of the structure proposed is shown in Figure 8.

Qualitative Discussion

The geological cross-section could be deduced by smoothing out the step-like decrements; this results in a structure in the form of a circular basin having a core of dense basic gneisses, surrounded by rocks having an intermediate density, the country rock being predominantly granite gneiss.

Deviations from this simple structure are noted as follows:

(i) In the northeast, around Ahmic Lake, the gravity contours are crowded together more, and a radial profile through this region would have a steeper gradient than elsewhere. It is suggested that the northeastern limit of the basin is dipping at a steeper angle than elsewhere.

(ii) In the southwest, near Parry Sound, the isogals swing away from their normal circular shape and parallel the outcrop of the hornblende gneiss shown on Satterly's map. By removing the "regional" effect due to the general basin structure, and assuming the gneisses to have the shape of a rectangular slab, a depth of about one and a half miles was obtained for their vertical extent.

(iii) In the area around Doe Lake, to the east of the main anomaly, the -30 milligal contour is deflected from its normal circular shape. This deflection coincides with an outcrop of biotite gneiss. Since the -25 milligal contour does not appear to be affected by these rocks, it is assumed that they represent only a thin layer covering the granitic gneiss, and are in fact an outlier from the main body of basic gneisses. It would also appear from the gravity map that the outcrop of biotite gneisses could be extended further to the southeast into the unmapped region.

Geological Evidence

The surface geology as mapped on the ground has been shown to consist of a wide variety of rock types with a complex structure. Satterly's map gives some indication of the major areas of outcrop of the three main rock types.

An interpretation of aerial photographs, however, suggests that many of the complexities of structure are only of local significance and that major trends may be picked out. It is believed that the evidence of these major trends corroborates the evidence for a basin shaped structure of the basic gneisses, admittedly oversimplified, in the analysis of the gravity and density data. In the southwest in particular, measurements of dip made in the field confirmed the idea of a synclinal extension of the more basic gneisses; elsewhere, insufficient dip determinations and the uncertainties due to the local contortions in the rocks make it impossible to relate with certainty the foliation pattern to the limbs of the synclinal basin.

Satterly suggested, on the basis of an examination of thin sections of selected samples, that the biotite and hornblende gneisses were metamorphosed sediments, with little or no introduced material, whereas the granite gneisses represented granitized sediments formed by the introduction of feldspathic material. The intermediate zone of densities may then be regarded as a transition zone between the two.

CONCLUSIONS

1. pre-Cambrian gneisses in the Parry Sound area show a wide variation in density. Values for the most basic gneisses often exceed 3.00 gm/cc, while values of the more granitic types may be as low as 2.60 gm/cc.

2. It was possible in this case, from a statistical study of rock densities combined with an analysis of the gravity observations, to compute the average densities of the rock structure causing the anomaly. This was done in an area of Archean-type Grenville rocks whose geology is complex and imperfectly known.

3. The greater part of the Parry Sound anomaly could be explained in terms of a nearly circular basin outcropping at the surface. The geological evidence, although not conclusive, supports the proposed structure.

4. The origin of the regional effect, whether it be due to crustal warping or whether it itself is due to density variations near the surface, may only be settled after more detailed density sampling over wide areas of the Shield has been undertaken.

5. Had the area been overlain with a sedimentary cover, and had bore holes penetrated to the basement, then the scattered density determinations made from the well cores would be valueless in attempting a gravity interpretation. A large number of specimens and a statistical study is necessary in such areas of Archean-type rocks.

ACKNOWLEDGEMENTS

The writer wishes to thank Professor J. T. Wilson and Dr. G. D. Garland for their unceasing interest and help at all stages of the work, and to thank Angela Burlinson for permission to publish, in Figure 4, the pattern of foliation which she plotted from aerial photographs. Rosamund Jackson, Brenda Oldham, and Alex Aitken assisted in the preparation of the manuscript.

He also wishes to thank the Worshipful Company of Goldsmiths for the award of an overseas scholarship permitting him to study at the University of Toronto. The field work was made possible by a grant from Imperial Oil Limited.

REFERENCES

Fitzpatrick, M. M., 1950, A gravitational study of the Clare River syncline area, Ontario: Trans. Royal Soc. Canada, v. 44, ser. 3, sect. 4, p. 21–34.

Garland, G. D., 1950, Interpretation of gravimetric and magnetic anomalies on traverses in the Canadian Shield of northern Ontario: Publ. Domin. Obs., v. 16, no. 1.

———, 1951, Comparisons of gravitational and magnetic anomalies over certain structures in southeastern Ontario: Can. Min. and Met. Bull., v. 54, p. 340–345.

Innes, M. J. S., 1952, Some structural features of the pre-Cambrian shield as revealed by gravity anomalies: unpublished Ph.D. thesis, University of Toronto.

Nettleton, L. L., 1942, Gravity and magnetic calculations: Geophysics, v. 7, p. 293–310.

Pelini, B., 1930, Tavola del potenziale di una lamina magnetica con orle circolare: Reale Accademia Nazionale Dei Lincei, v. 12.

Prendergast, J. B., 1951, Interpretation and geological correlation of regional gravity effects in southern Ontario: unpublished M.A. thesis, University of Toronto.

Satterly, J., 1942, Mineral occurrences in the Parry Sound district: Publication of the Ontario Dept. of Mines, v. 5, part 2.

Uffen, R., 1950, Gravitational and geological study of the Grenville and Superior Provinces: unpublished M.A. thesis. University of Toronto.

Weatherburn, C. E., 1949, A first course in mathematical statistics: Cambridge, Cambridge University Press.

GRAVITY MAXIMA CORRESPONDING WITH SEDIMENTARY BASINS*

RODOLFO MARTIN†

ABSTRACT

Gravity work in Argentina has shown maximal values over the deepest part of some sedimentary basins. It is suggested that this unexpected result may be explained as a case of imperfect isostatic adjustment and may be of general interest in the interpretation of gravimetric surveys. It is also suggested that Airy's theory gives a better explanation of isostatic compensation over moderately large areas while the Pratt theory is applicable to enormous regions, of continental extent.

Gravimetric work in the search for oil, carried out over a number of years, on the broad and almost perfectly flat Argentine pampas and on the extensive plateaus of Patagonia, gave unexpected results when well defined maxima were found over the center of what had previously been established as deep sedimentary basins.

The well developed basins under the plains of Argentina are concealed by a cover of recent formations. Some of these basins were known or suspected earlier but the larger number were indicated through seismic refraction surveys. Since these constituted prospectively favorable areas for oil accumulation, gravimetric, magnetic, and seismic reflection surveys were carried out over them.

Some of the basins appear as gravity minima, but, rather surprisingly, others appear as gravity maxima. There is no possibility of attributing the unexpected results to inaccuracies of measurement, as every precaution has been taken to avoid errors. Modern instruments (gravimeters of 0.01 mg accuracy) were used, and drift, calibration, and closures were considered carefully. The basins referred to had been outlined by seismic refraction work and, much later, wells drilled on the geophysical evidence closely checked the refraction results.

Figures 1 and 2 show gravity contours and a cross section in the Rio Salado Basin, which is located immediately south of the city of Buenos Aires. Figure 1 shows gravity contours at a 5.0 mg. interval. Figure 2 shows the basement profile along line A-A' in the western part of the basin, the corresponding gravity profile, and the surface terrain. This area is very flat with the exception of the Tandil Hills to the south and the Uruguay Hills to the north, across the La Plata River. The basement outcrops at both of these hills. A well was drilled in the central part of this basin to a depth of greater than 12,000 ft without finding the basement.

* Manuscript received by the Editor August 14, 1953.

† Argentine Government Owned Oil Fields, Buenos Aires, Argentina. Now with Geophysical Service Incorporated, Dallas, Texas.

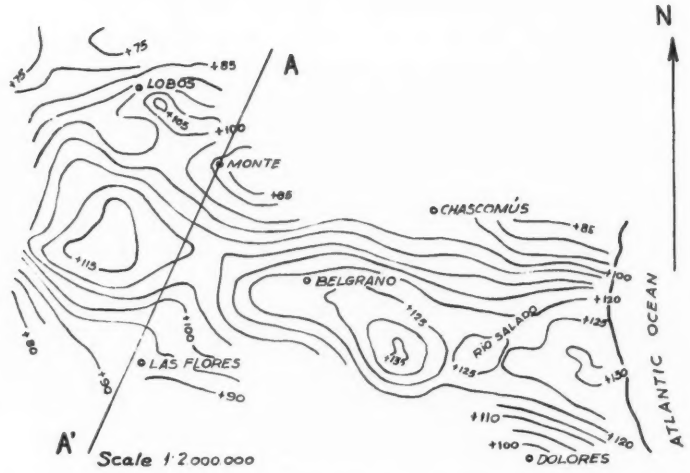


FIG. 1. Gravity contours in Rio Salado Basin, Argentina, immediately south of Buenos Aires. Contour interval is 5 mg.

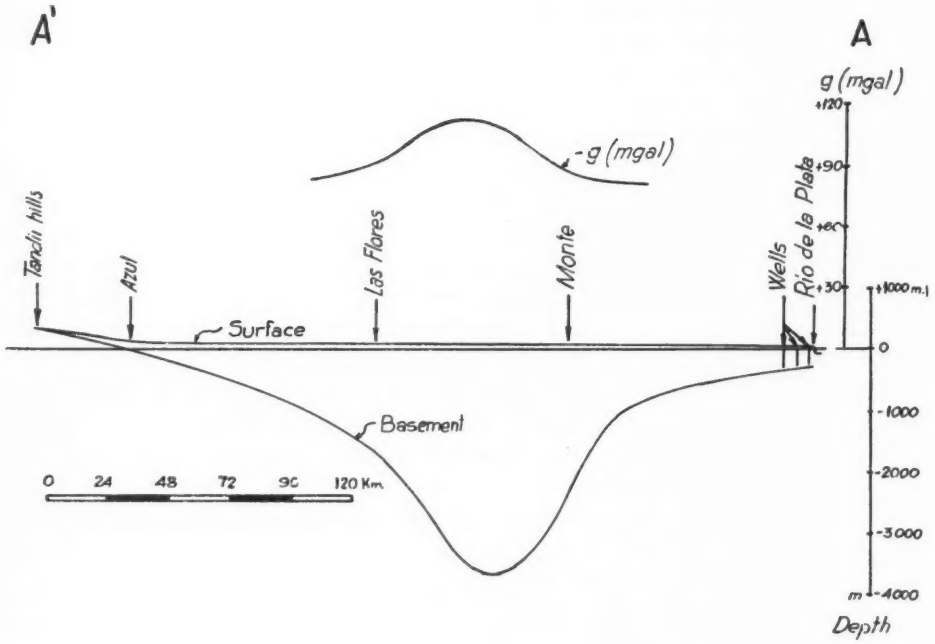


FIG. 2. Gravity cross section, surface topography, and basement configuration along profile AA′ of Figure 1.

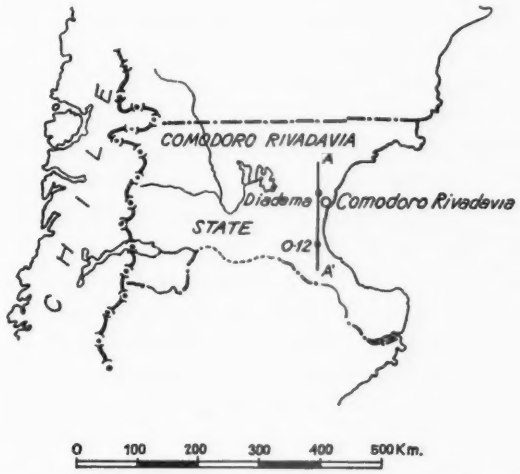


FIG. 3. Index map of the San Jorge Basin, Comodoro Rivadavia area, Argentina.

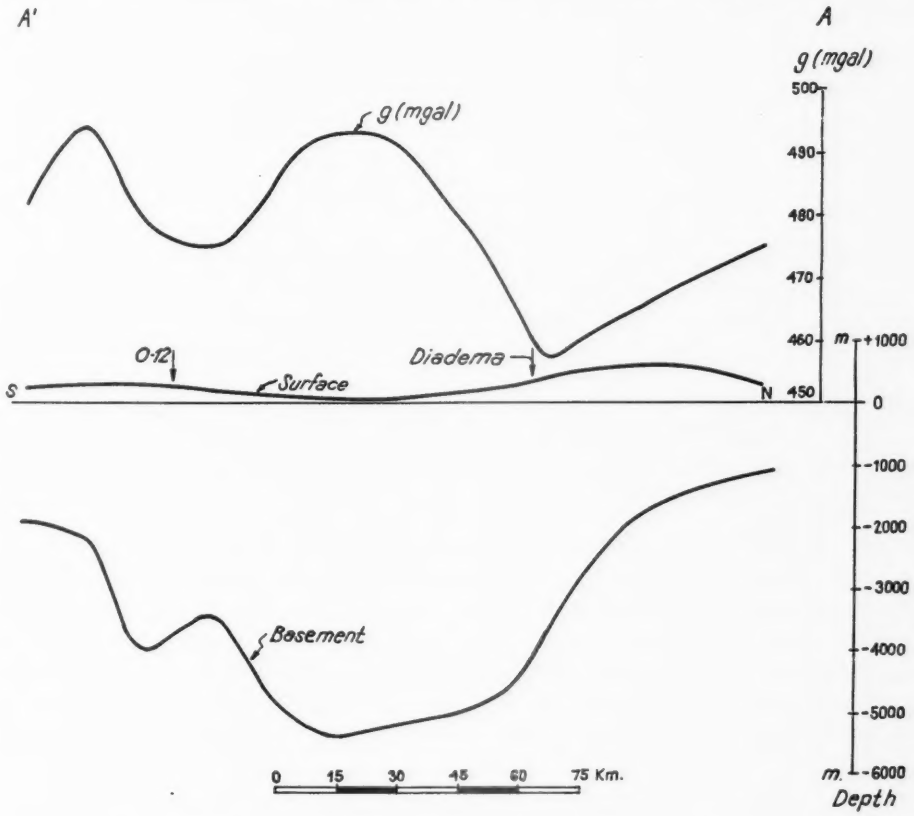


FIG. 4. Gravity cross section, surface topography, and basement configuration along profile AA′ of Figure 3.

Figure 3 is an index map of the San Jorge Basin, in the Comodoro Rivadavia area on the Atlantic coast, and Figure 4 shows basement and gravity profiles on a north-south line across the basin.

It is the author's belief that an explanation of the gravity maxima over the basins (though probably not the only one) can be given on the assumption that, at a time before the sediments were laid down, isostatic compensation had taken place between the elevated blocks on the side and the depressed blocks in the center which formed the basin. Later on, sediments filled the basin but no further isostatic adjustment took place, either on account of insufficient time having elapsed or because of increased rigidity of the earth's crust. The weight of the sediments would now be supported by the rigidity of the crust and the excess mass due to the sedimentary deposition in the compensated areas would produce the positive gravimetric anomaly which is now observed.

Figure 5 shows these two stages schematically on the assumption that Airy's hypothesis is valid; this is considered reasonable because we have no reason for postulating different densities on the elevated and the depressed blocks of the basement as would be required by Pratt's hypothesis.

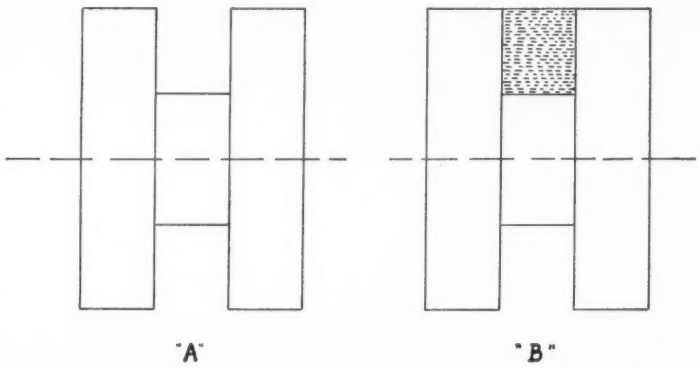


FIG. 5. Blocks on the left (A) are in isostatic equilibrium according to Airy hypothesis. Basin represented by center block. Later basin fills up with sediments (represented by stippled zone in B) but there is no isostatic readjustment.

In the case of the Rio Salado Basin (Figures 1 and 2) the basement of very old Paleozoic and Archean rocks outcrops or is very shallow at the basin edges, as is indicated by Figure 2. The sediments in the basin are upper Cretaceous or later; they are mostly marine, but some are continental. The surface is now close to sea level so that the bottom of the Basin is at a great depth below sea level. We do not know whether the Basin may have been emergent during its history, at times of general uplift, or if its present depth is the result of repeated or continuous subsidence.

A somewhat similar situation exists at the San Jorge Basin. Here the basement consists of porphyries and volcanic tuffs of upper Paleozoic or early Mesozoic

age, and outcrops north and south of the basin. The sediments are partly marine and partly continental.

As can be seen from the scales of the illustrations, the size of the area involved in both these examples is of the order of tens of kilometers in the narrow dimension. Under the writer's assumption, areas of such comparatively small extent would be isostatically compensated at an earlier stage in these examples. This suggestion may be of interest in relation to gravimetric prospecting and interpretation, as the possibility of such effects should be taken into consideration in developing regional corrections, separation of anomalies, the interpretation of features at depth, etc.

It is suggested that both the Airy and Pratt theories of compensation are correct but under different circumstances. Airy's theory may be valid when moderate areas are involved, with rocks of equal densities in the different blocks. Pratt's theory may be more applicable to the adjustment of very large areas where the different blocks could have unequal densities (such as in the bottoms of oceans and floors of continents or between mountain chains and adjacent plains, etc.). Neither theory is free of objections but the views suggested here may remove some of the difficulties.

The author is indebted to the higher officials of the Y.P.F. (Argentine Government Oil Fields), Mr. J. B. Siri, General Manager, Dr. O. I. Bracaccini, Technical Manager, and Mr. J. Zunino, Exploration Manager, for permission to publish this paper.

DISCUSSION BY PAUL C. WUENSCHEL*

The author calls attention to examples of positive Bouguer anomalies over sedimentary basins and suggests a possible interpretation for them. The present reviewer questions this interpretation and contends that, in the case of the Rio Salado Basin, the calculated anomaly based on this method of interpretation will not reproduce the observed anomaly.

One can appreciate this conclusion if he considers how this calculation is made. In the following discussion the Airy type crustal structure will be used. Compensation for the valley having the cross section of the Basin will be placed at the base of a 40 km crust. The valley will then be filled with sediments, as suggested in the author's theory. The density of these sediments will be taken as 2.5 g/cc. Since the rock forming the Sierra Tandil will have a density of approximately 2.67 g/cc, the Basin will be characterized by a mass deficiency. Thus the crustal column is much too heavy, with the bulk of the mass excess at the base of the crust rather than at the top. The calculated anomaly for the mass deficiency at the surface and the much greater mass excess at the base of the crust would be characterized by a large positive anomaly approximately 170 mg in

* Research Inc., Dallas, Tex. The author of this discussion recently ran and interpreted a 2,000-station regional gravity survey of South America for his Ph.D. dissertation at Columbia University—*The Editor.*

magnitude and by an anomaly width at least as wide as the Basin's diameter.

Reference to the anomaly curve in Figure 2 shows that this description does not fit the observed anomaly curve. Instead the positive anomaly has a magnitude of approximately 30 mg and a half-width of 27 km. If a correction is made for the mass deficiency of the basin and for its compensation the observed anomaly is increased in magnitude to 42 mg and the half-width is increased slightly to 28.4 km.

By the standard depth determination methods we can state that the maximum depth to the center of gravity of the disturbing mass, if we consider the geometry of this mass to be a horizontal cylinder, is approximately 28.4 km and the radius of the cylinder would be 6.9 km for a density contrast of 0.6 g/cc. Thus the disturbing mass may exist anywhere within or at the base of the crust. The horizontal extent of the cylinder of only 13.8 km diameter, when placed at the base of the crust, does not allow us to consider it as compensation for a basin whose average width is approximately 100 km.

The profile shown in Figure 4 is less convincing than that shown in Figure 2. Additional reduction to the Bouguer anomaly should be done prior to its interpretation. By considering the compensation for the topography in the northern and southern portions of the profile, the negative excursions near Diadema and 0.12 may be reduced. The sharp curvatures in the anomaly curve indicate their cause to be of shallow origin. A three-dimensional isostatic reduction may further reduce the broad maximum over the basin. The remaining anomaly can then confidently be interpreted as an undercompensation for the basin.

REPLY BY MR. MARTIN

The author has read Dr. Wuenschel's discussion with great interest and has the following comment. If the system was compensated before the deposition of sediments in the basin, the mass of the sediments will be in excess rather than in deficit. This view is in agreement with the fact that the mass excess is compatible with the magnitude and size of the anomaly assuming partial compensation, as can be shown by integrating under the anomaly curve.

GRAVITY CASE HISTORY: DAWN NO. 156 POOL, ONTARIO*

RICHARD A. POHLY†

ABSTRACT

The Dawn No. 156 pool in southwestern Ontario was discovered by the Union Gas Company of Canada Limited, in January, 1952, by drilling on a gravity maximum. The drilling supported the original interpretation that this maximum was produced by a Silurian reef. Initial production of 6.5 million cubic feet per day was obtained from the upper fourteen feet of the Guelph in highly porous reef dolomite at a depth from 1,720 to 1,734 feet below the surface.

The geology of the area is discussed as a background for the gravity interpretation. Bouguer and residual gravity maps of the original survey are presented.

INTRODUCTION

The Dawn No. 156 pool in Lambton County, Ontario, was discovered by the Union Gas Company of Canada in January of 1952, upon drilling one of several recommended anomalies which had been mapped by a Seismograph Service Corporation gravity crew during the summer of 1951. It was chosen as the subject for a case history for two reasons. In the first place, it is a typical Niagaran reef of the pinnacle type which is so common in the Illinois Basin and presumably in the Michigan Basin. In the second place, the gravity anomaly is a good example of the average anomaly to be expected from this type of reef. It also has the advantage of being a discovery drilled entirely upon gravity information, and should therefore add somewhat to the prestige of the gravity method as a means of providing accurate direction for the drill in reef areas.

The writer would like to take this opportunity to acknowledge the assistance of Dr. Charles S. Evans, Chief Geologist for the Union Gas Company of Canada, in providing the geological data for this paper. In fact, much of the success of the original survey was attributable to his extensive knowledge of salt thicknesses, distribution of glacial drift, and other factors which can be serious problems in gravity interpretation in any area. We would also like to thank the Union Gas Company of Canada for its permission to release the gravity information included in this paper.

Since many excellent papers have been published on the geology of the area (Roliff, 1949; Williams, 1919; Evans, 1950), we will limit our discussion to the geological features which are pertinent to the gravity problem. The mathematical treatment of the anomaly would be of scant importance in reef problems. The density of reef limestone is a function of the porosity, and density distribution in these reefs can vary so greatly that anomalies of almost any intensity may be found to occur in conjunction with reefs of various sizes. There appears to be no relationship between the intensity of a reef gravity anomaly and the size of a

* Presented at the Midwestern Regional Meeting of the Society at Fort Worth, November 13, 1952. Manuscript received by the Editor August 8, 1953.

† Seismograph Service Corporation, Tulsa, Okla. Now with Pohly Exploration Co., Tulsa, Okla.

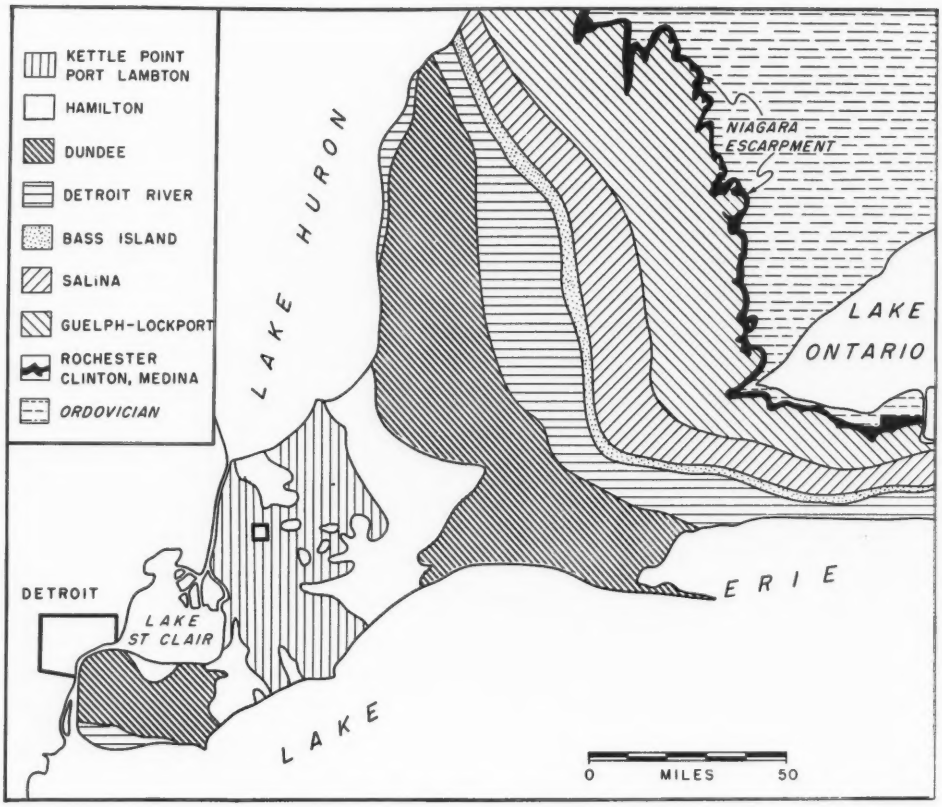


FIG. 1. Geological map of southwestern Ontario.

reef. It is therefore necessary that any gravity interpretation be almost exclusively qualitative. This has frequently been pointed out as a serious deficiency in the method, but one of the purposes of this paper is to show that the quantitative analysis of a gravity anomaly is not nearly as important as a qualitative approach where reefs are concerned.

THE AREA

Figure 1 shows a geological map of southwestern Ontario, after Evans (1950), with the box indicating the area under discussion. Geologically, it is on the extreme southeastern slope of the Michigan Basin, with the axis of the Cincinnati Arch passing along the north shore of Lake Erie, and the Appalachian Basin extending southeastward from that. The surface rocks range in age from Devonian, in the Lambton County area, to Ordovician, east of the Niagaran Escarpment. In the western part of the peninsula outcrops are few in number, with the bedrock being covered by 50 to 300 feet of glacial drift.

Figure 2 is a generalized columnar section after Roliff (1949), showing the

GENERALIZED COLUMNAR SECTION
SOUTHWESTERN ONTARIO
AFTER W A ROLIFF

	MICHIGAN TERMS	ONTARIO TERMS
DEVONIAN	ANTRIM	PORT LAMBTON KETTLE POINT
	TRAVERSE	HAMILTON
	DUNDEE	DUNDEE EQUIVALENT
	DETROIT RIVER SYLVANIA BOIS BLANC	DETROIT RIVER & OLDER DEVONIAN
SILURIAN	BASS ISLAND	BASS ISLAND
	SALINA	SALINA
	LOCKPORT	GUELPH–LOCKPORT
	BURNT BLUFF AND CATARACT	ROCHESTER
		CLINTON
		MEDINA (GRIMSBY, MANITOULIN, CABOT HEAD WHIRLPOOL)
ORDOVICIAN	QUEENSTON	QUEENSTON
	LORRAINE	MEAFORD-DUNDAS
	UTICA	BLUE MT.–COLLINGWOOD
	TRENTON – BLACK RIVER	TRENTON–BLACK RIVER
	GLENWOOD	BASAL BEDS (QUITE THIN – MOSTLY DIRECT DETRITUS OF UNDERLYING PRE-CAMBRIAN)
	ST. PETER	
CAMBRIAN	TREMPEALEAU	
	FRANCONIA	
	DRESBACH	
	EAU CLAIRE	
	MT SIMON	

FIG. 2. Generalized columnar section of southwestern Ontario.

sequence of formations designated both in the Michigan and Ontario nomenclatures. To the gravity interpreter, the *average* density of the beds in such a section is extremely important, and the success of a gravity survey depends entirely upon the proper evaluation of the density contrasts to be expected, not only in the productive horizons, but in any horizon from the surface downward. For that reason, the field survey must be planned in such a way that it will give data which should make it possible to evaluate the effects of the important density changes.

In the immediate vicinity of the Dawn No. 156 pool, the surface material consists of approximately 80 feet of glacial lake fill. The surface is very flat. The evidence of many shallow wells in the area indicates that the surface of the bedrock is also relatively smooth. It therefore appears that drift should not give rise to a density problem, unless there are local accumulations of boulders or dense gravels. The Huron shale is the bedrock. The underlying Hamilton is also

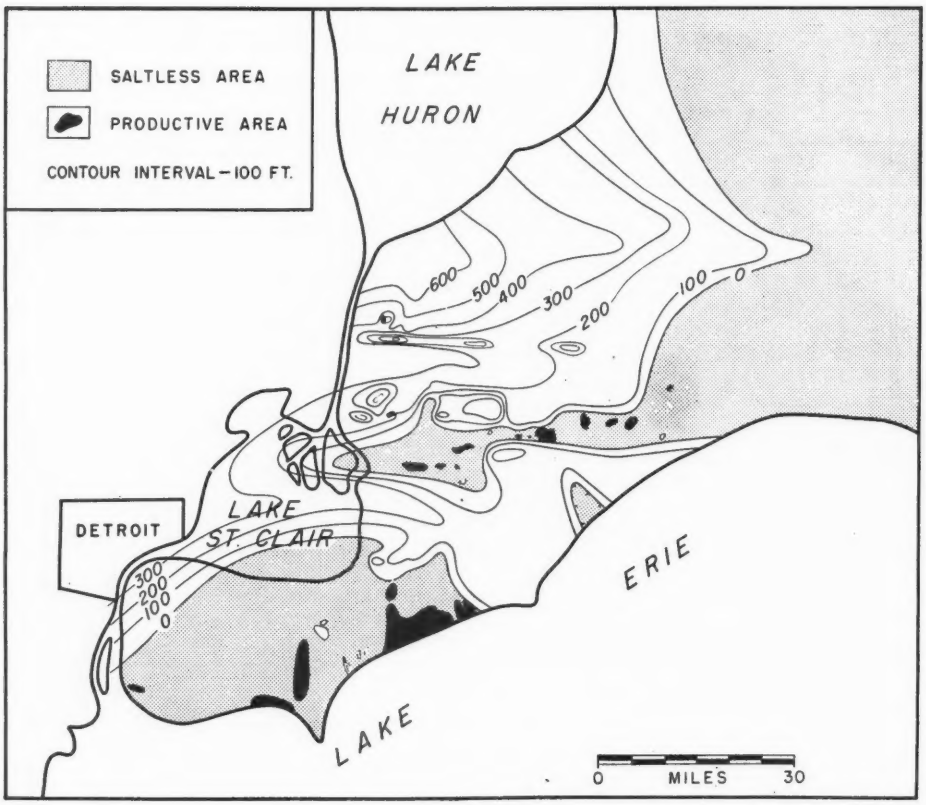


FIG. 3. Isopachs of total salt.

essentially a shale, with some limestone streaks. The Dundee is mostly limestone and, although a density contrast exists between the Hamilton shale and the Dundee limestone, the two are conformable, and it is probable that no interpretable gravity effects would result from this density contrast. The Detroit River and Bass Island are principally limestones and dolomites, so little density effect can be expected from this zone. The Salina, however, consists of dolomites, anhydrites and normally thick salt beds.

Figure 3 is a salt isopach map (Evans, 1950). The salt thickness is even more variable than it appears on this small scale map, and wherever the salt thins abruptly, there is a corresponding thickening of the limestones or dolomites. Since rock salt has a density of 2.2 and limestone an average density of 2.54 (Dobrin, 1952), it is apparent that gravity maxima will be produced wherever the salt thinning is sharply defined. It was considered that this might provide a serious problem in the gravity interpretation and it is possible that many of the anomalies which we have interpreted as reefing may be simply sharp local changes in the thickness of these salt beds. The one characteristic which may help to

differentiate the salt anomalies from those produced by Niagaran reefs is the shape of the anomaly itself. You will note that most of the salt thinning shown on this isopach appears to occur in elongate trends. This will be discussed in greater detail later in the paper.

Associated with the reefs in the area is a very sharp local thickening of the Guelph, over which the salt beds thin. This could be expected to produce a gravity maximum. It was therefore considered that our principal gravity anomalies would fall in three general categories: those which might be produced by local concentrations of dense gravels or boulders in the drift; those produced by local thinning of the salt; and those produced by the Niagaran reefs. There are, of course, in this area as in any other area, the large gravity features which stem from irregular mass distribution in the pre-Cambrian.

THE SURVEY

The program recommended for a gravity survey of this area, based on the known geology described in the previous paragraphs, required 1,000-foot spacing of gravity stations along all of the roads as a preliminary reconnaissance. This made it possible to cover the area in the most economical manner, and since the road network gave good coverage, the probability of any single reef occurring in a position where no effect would be noted on adjacent roads was relatively slight. However, extreme accuracy is required for this type of survey, since the situation frequently occurs where an outlying reef may affect the gravity values of only one or two stations.

The elevations of the stations were determined by spirit level traverses, and the maximum allowable error in closure was held to 0.5 ft. The locations of the stations were determined by transit traverses, employing magnetic bearings and stadia distances. The maximum allowable error in closure of these loops was limited to 100 ft, but since topographic maps were available, the horizontal control was carefully checked and adjusted to these maps, and it is probable that the location of each station is accurate within 25 ft.

The Worden gravity meter was used throughout the survey to determine the gravity differences of the stations. To assure a consistent gravity datum over the entire area, a base network was set up with bases approximately six miles apart and tied in a series of triangles in which each leg was double-run. Permissible error in closure of these triangles was held to a maximum of 0.03 milligals, with each triangle then adjusted to a zero closure. Individual stations were occupied by the meter during runs from a base not in excess of two hours. Meter drift was adjusted linearly as a function of time. Many old stations were re-occupied during each drift, which made it possible to keep a constant check on both the accuracy of our drift correction and the accuracy of the meter operator's reading.

Latitude corrections for each station were read from a transparent overlay scale, computed to give the value of theoretical gravity on the International Ellipsoid for any location in the area. An elevation correction factor of 0.070

mg/ft was determined by density profiles over topographic features in the area. However, for the most part the area was so flat that the elevation correction factor was of little importance.

It was considered that this type of control would give us adequate accuracy and coverage to detect any anomalies which might be situated in the areas between lines of stations. Whenever an anomaly was noted on our control lines, interior stations were secured to give additional detail.

REEF INTERPRETATION

Extensive gravity surveys over known Niagaran reefs in the Illinois Basin have established empirically that the gravity anomaly associated with a reef in that basin invariably consists of a central maximum with a surrounding minimum. This was discussed in detail in a paper presented by the writer at the 20th Annual Meeting of the SEG in Chicago in 1950 (Pohly, 1953). The reefs in the Illinois Basin, however, tend to have a much more definite detrital zone than

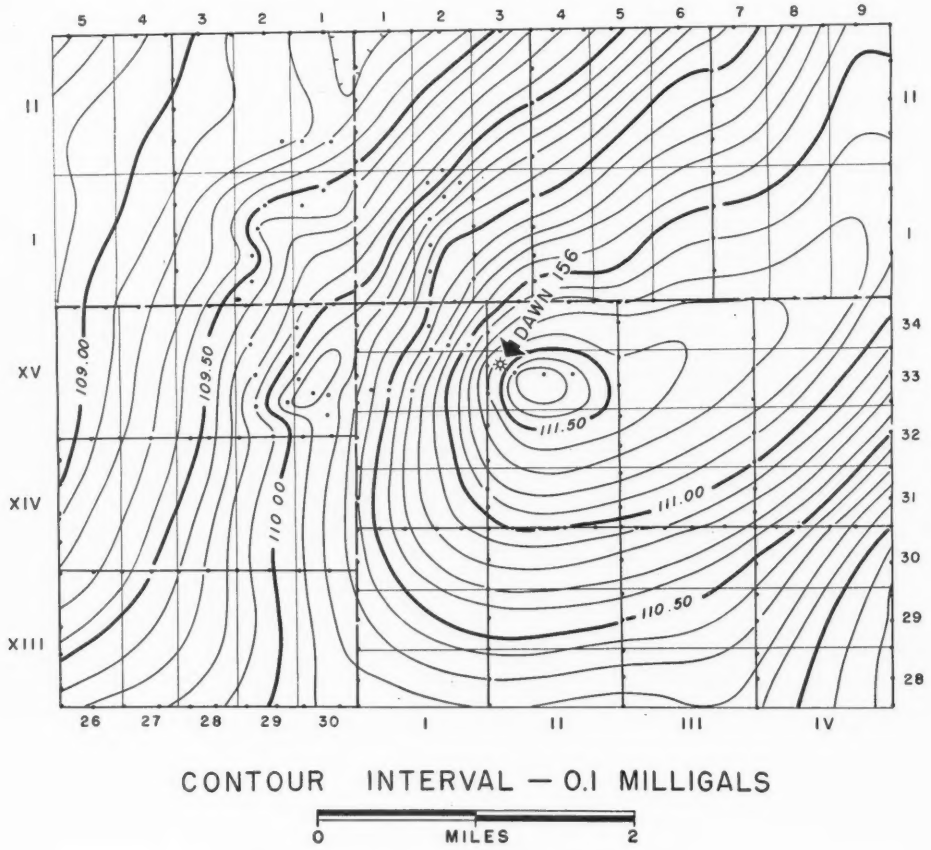


FIG. 4. Bouguer gravity map, Dawn 156 pool.

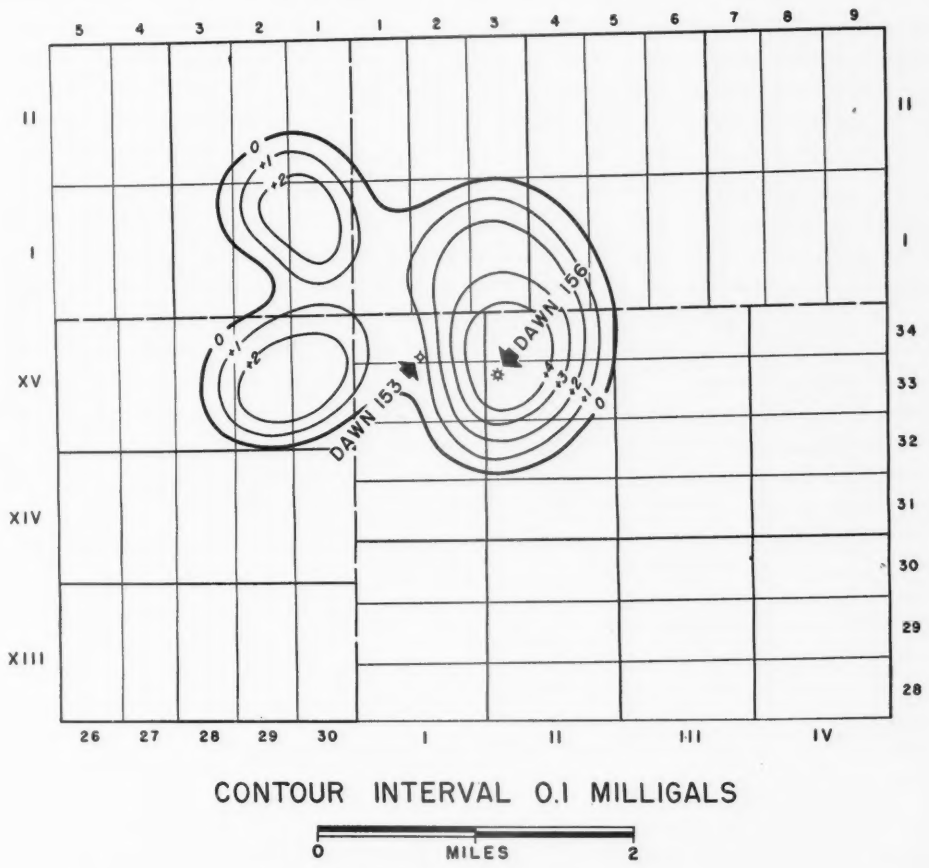


FIG. 5. Residual gravity map, Dawn 156 pool.

those in Ontario. Moreover, the lack of salt section in Illinois would make it appear probable that the Ontario reefs should produce a gravity anomaly consisting essentially of a maximum, with little or no surrounding minimum effect. As mentioned earlier in this paper, the local thinning of the salt would also produce gravity maxima, but the known salt features appeared to occur in relatively long trends on the salt isopach map. The pinnacle reefs, on the other hand, have exhibited a consistently circular shape, so it was decided that only those anomalies which showed little elongation in the gravity maximum could be interpreted as reefing with any reliability.

Figure 4 shows the Bouguer gravity map of the area surrounding the Dawn No. 156. It will be noted that the well is located in a small bulge on the edge of a large gravity maximum. It is considered that most of this large maximum is produced by a broad local thinning of the salt beds, and its effect should be removed by making a residual map which would indicate only the significant anomalies. Figure 5 shows such a map. A smooth contour map was first constructed simply

by smoothing the contours of the Bouguer map to fit the apparent regional gravity grain. Values were interpolated from this smooth contour map at station locations and subtracted from the Bouguer values. The residual was then constructed by contouring these differences. It is obvious that such a residual method is completely dependent upon the judgment of the interpreter and its reliability has frequently been questioned by mathematicians. However, it is the author's belief that this sort of treatment secures better results in the hands of an interpreter who has had extensive experience in reef problems than a mathematical treatment which, in most areas, produces a large number of pseudo-maxima. The anomaly shown on this map was originally interpreted as evidence of a reef, and a recommendation was made that a well be drilled within the closing plus 4 contour of the principal portion of the anomaly. The two +2 anomalies to the west were considered as equally valid reef possibilities in the report.

On December 12, 1951, a well was commenced at the location indicated. The location is described as 400 feet south of the north lot line and 450 feet east of the west lot line of Lot 33, Concession 2, Dawn Township, Lambton County,

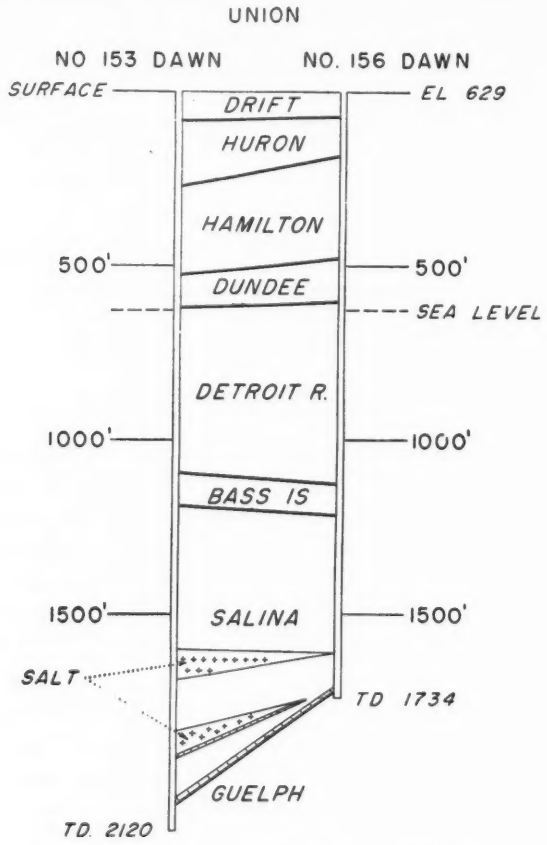


FIG. 6. Cross-section through Dawn 153 and Dawn 156.

Ontario, on the farm of N. F. and V. D. Wilson. It was completed on January 15, 1952, at a total depth of 1,734 feet. The Guelph was encountered at 1,720 feet. Initial production was 6,014,300 cubic feet of natural gas per day. At a point 2,600 feet west and slightly north of this location there is a dry hole, known as the Dawn No. 153, which provides a good comparison between a reef well and one with normal salt section.

Figure 6 shows a cross section, comparing the tops of formations in the two wells. No details of lithology are included in these sections, but the composition of the formations was very similar down to the Salina. In the Salina two thick salt beds which were present in the Dawn No. 153 were absent in the Dawn No. 156. The character of the Guelph was also very different. The Dawn No. 153 penetrated 79 feet of Guelph, which consisted of medium gray and buff dolomite with low porosity. The Dawn No. 156 penetrated only 14 feet of Guelph, with the upper two feet being a medium granular to crystalline, porous buff brown dolomite. The remaining 12 feet was buff brown reef dolomite with high but irregularly distributed porosity. This portion of the section was partly cavernous. Another very interesting feature of the comparison between the two wells is the fact that the Bass Island top was lower over the reef than it was in the dry hole. This probably accounts for the fact that many of the wells in the Michigan Basin have been abandoned short of the Niagaran or Guelph. However, according to Dr. Evans, this condition occurs very frequently in the area. It also points up the fact that some geophysical method is required to locate the Niagaran reefs, since core holes drilled to shallower formations would give no indication of their presence.

CONCLUSION

The shallow depth of these reefs, plus the sharp density contrast between salt and reef limestone, provides a very favorable situation for gravity and accounts for much of the success of the method in that area. Prior to April, 1953, seven wildcat wells had been drilled on gravity anomalies. Five of these wells have found reefs. Of the remaining two wells, one encountered a sharp local thinning of salt, which accounted for the gravity anomaly; the other had no variation in section which could account for the anomaly; and we must assume that it was most probably produced by a local increase in densities in the glacial drift.

REFERENCES

Evans, C. S., 1950, Underground hunting in the Silurian of southwestern Ontario: Proceedings Geol. Assoc. Can., v. 3, p. 56.

Roliff, W. A., 1949, Salina-Guelph fields of southwestern Ontario: Bull. A.A.P.G., v. 33, no. 2, p. 158.

Pohly, R. A., 1953, New gravity approach aids reef interpretation: World Oil, v. 136, no. 6, p. 116–124.

Williams, M. Y., 1919, The Silurian geology and faunas of Ontario peninsula: Geol. Surv. Can., Memoir 111.

Dobrin, M. B., 1952, Introduction to geophysical prospecting: New York, McGraw-Hill Book Co., Inc.

SEISMIC RECORDING ON MAGNETIC TAPE*

G. B. LOPER† AND R. R. PITTMAN†‡

ABSTRACT

A system of recording and reproducing exploration seismograms on magnetic tape is described. Geophones and amplifiers with broad-band response, approximately 4–300 cps, are used to channel the seismic signals to a 13-track tape recorder. The magnetic tape is 1 inch wide. One of the tracks is used to record a time reference signal. Each broad-band recording is formed into an endless loop and played back in repeating fashion. The signals are fed through a flexible system of filtering and mixing, then examined on the screen of a 12-trace cathode-ray oscilloscope. The sweep of the oscilloscope is synchronized with the loop and, by varying the sweep speed, the entire record, or an expanded portion thereof, is held stationary on the screen. Conventional paper records of the modified record as reproduced on the screen are finally made with a regular seismic camera. Played-back records with variations of filtering and mixing are shown in order to illustrate the potential usefulness of the technique.

INTRODUCTION

The rapid strides made since the end of World War II in the magnetic recording of sound have given a great deal of impetus to the development of techniques for reproducible recording of seismic signals. Such techniques, which have been experimented with for more than 15 years, involve the recording of seismograms on a medium which can be played back to regenerate the original electrical signals. Many seismologists have felt that such techniques offer many benefits but until recently practical considerations have limited activity in the field to a few experimental operations. Some of these experiments in reproducible recording have been described by Jakosky and Jakosky (1952).

As more and more effort has gone into experimental shooting to discover ways of gleaning usable data from formerly unsatisfactory areas, the desirability of high-fidelity reproducible records has become obvious. Such records lend themselves very well to the variety of analyses that an experimental group may want to make.

The equipment to be described in this paper has had just such a background. It was assembled by the seismic group of the Magnolia Petroleum Company's Field Research Laboratories as a research tool to aid in fundamental studies on the seismic method of oil exploration.

Most previous work with reproducible seismic records involved the use of photographic film or paper which was exposed to seismic galvanometer spots, or to beams from special recording lamps, in such a way as to yield variable-area or variable-density traces. These records could then be played back by means of a photoelectric-optical scanning device. Careful photographic development of the

* Presented at the Annual Meeting of the Society at Los Angeles on March 26, 1952 and at the Midwestern Regional Meeting at Forth Worth on November 14, 1952. Manuscript received by the Editor October 2, 1953.

† Magnolia Petroleum Company, Field Research Laboratories, Dallas, Texas.

‡ Now with Century Geophysical Corporation, Tulsa, Oklahoma.

records in this case is generally necessary to avoid scratching and fogging, and, in the case of the variable-density technique, to assure that a linear density-versus-signal-amplitude recording results. These are critical requirements to meet and maintain under field conditions. On the other hand, magnetic recording, with its lack of optical and chemical problems and with its inherent insensitivity to rough handling, is attractive for the production of reproducible seismograms.

RECORDING EQUIPMENT

Construction

The magnetic recording system to be described here was adapted to our specifications by the Ampex Electric Corporation of Redwood City, California from commercial equipment that had been primarily developed for audio recording and telemetering. The recorder is shown in Figure 1. The magnetic tape, which is of the regular plastic type coated with red oxide of iron, is one inch in width and is stored on the lower reel. The tape passes at 30 inches per second over the re-

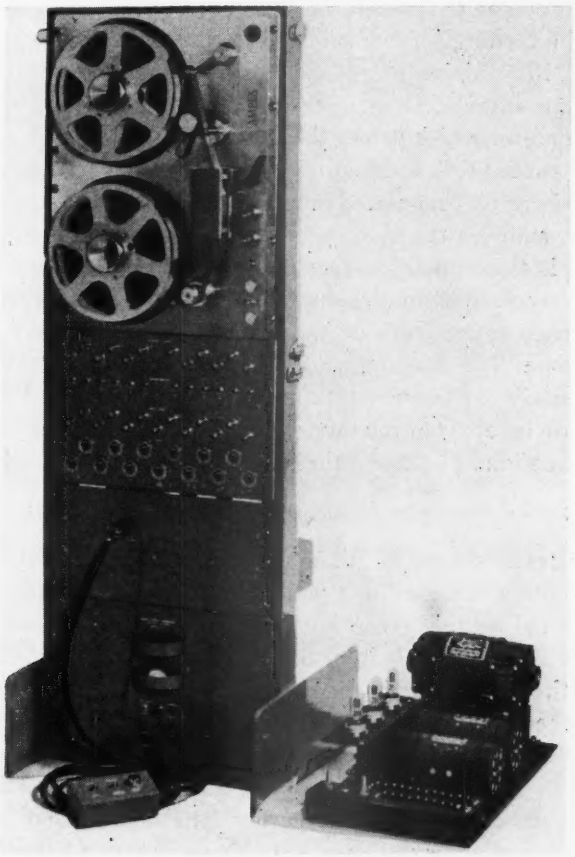


FIG. 1. Magnetic recording unit for use in seismic field truck.

cording heads, against the capstan which is the prime mover for the tape during recording, and on to the take-up spool above. The storage and take-up spools are motor driven to keep the tape taut, and the motors may be used to wind the tape rapidly from one spool to another. Successful recordings may also be made at a tape speed of 15 inches per second.

This equipment records thirteen independent channels of information. There are thirteen heads spaced in succession from one side of the tape to the other. Twelve of these are used to record seismic signals, and the thirteenth records an accurate steady signal of fixed frequency to serve as a time reference. A frequency modulation system is used to modulate the tape. A ten-kilocycle carrier of approximately square wave-form is impressed on each of the twelve information channels. These carriers are generated by twelve oscillators in the modulation unit shown just below the tape drive mechanism in Figure 1. The twelve seismic signals enter the modulator at the plugs on the front panel and vary the frequencies of the oscillators in proportion to the vibration amplitude that would normally be recorded on the conventional seismic camera. At a speed of 30 inches per second, the recordings of each shot are 10 to 15 feet long, plus another 12 feet that is used in attaining proper recording speed. The system is much more economical of tape and electric power when recording at 15 inches per second.

The capstan motor which drives the tape is an ac motor receiving its power from a 60-cycle tuning fork oscillator and power amplifier shown at the bottom of the rack in Figure 1. A regulated power supply, shown just above the capstan power amplifier, supplies the modulator circuits with stable voltages. A 12-volt storage battery is the primary source of power. The necessary higher voltages come from the 12-volt dynamotors shown to the right. This recording system will handle a frequency range from dc to 300 cps with relatively flat phase and amplitude response. The maximum useful signal amplitude to be recorded produces approximately one percent total harmonic distortion in the magnetic tape system. The noise inherent in the tape system is somewhat less than a hundredth of this. Thus, the signal-to-noise ratio is slightly more than 40 db.

Use in the Field

Figure 2 illustrates the use of this equipment in seismic research. The magnetic recorder is separately mounted in a panel truck which is usually parked in front of the conventional seismic recording truck. The cables shown connecting the trucks carry the seismic signals from the outputs of the amplifiers in the conventional truck to the modulators in the magnetic recording truck where they are recorded during the shot. A regular paper record is made in the first truck simultaneously with the magnetic record in the second truck. The geophones and amplifiers used in this system will pass frequencies from 4 cps up, the high end being limited at 300 cps by the tape recorder. Although some of the research geophones are capable of 4 cps response, geophones having a lower limit of about 6 cps are used for multiple-phone work.

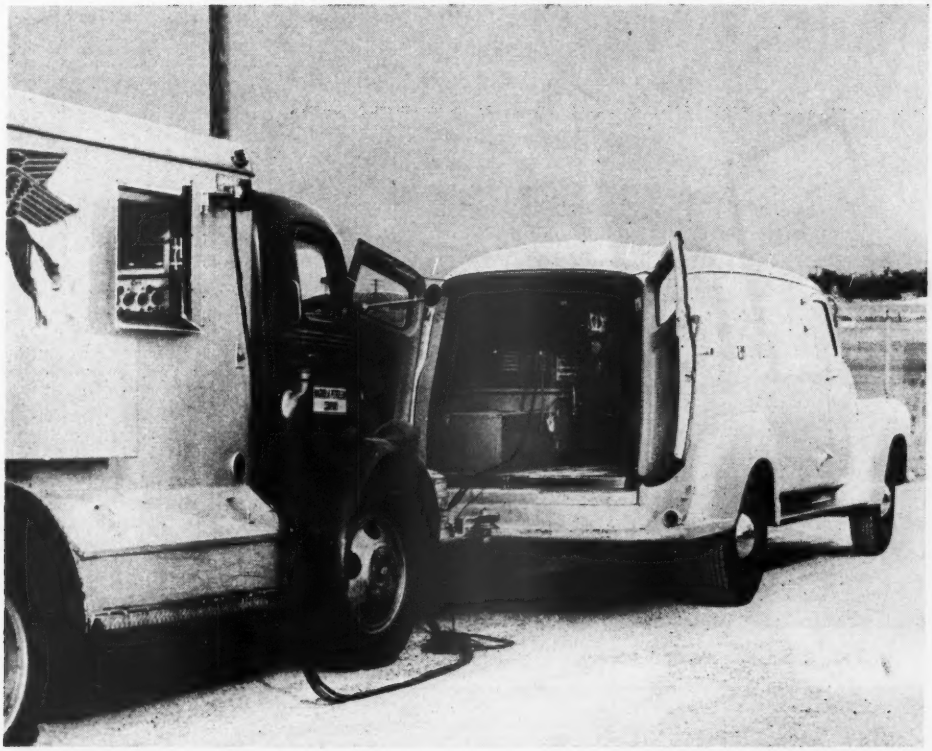


FIG. 2. Tandem operation of field magnetic tape recorder with conventional seismic recording truck.

When a magnetic record is made, a minimum of filtering is used. Generally, the high frequency end is left wide open. The low frequency cutoff is determined by the nature of the signals to be examined. If low frequency ground roll or surface waves are to be examined, the low frequency response is left wide open. If reflections, which are frequently obscured by ground roll, are to be examined, some discrimination against ground roll is introduced with filters which raise the low frequency cutoff to the point where the normal band of reflection frequencies is recorded. Wide flexibility of filtering is not needed, as this function will be performed upon play-back of the tape.

The use of two recording trucks is quite unnecessary. Suitable seismic amplifiers may easily be incorporated into one truck with the magnetic tape equipment. An installation of this type is shown in Figures 3 and 4. Here is shown a 1-ton panel truck which has been adapted to take dual rear tires or balloon tires for improved traction in muddy and sandy terrain. This is a complete recording truck requiring only geophones, cables, and the usual shooting truck for making 12-trace seismograms on magnetic tape. The interior is light, well ventilated, and is devoid of development pots and chemicals. The signals recorded on the magnetic

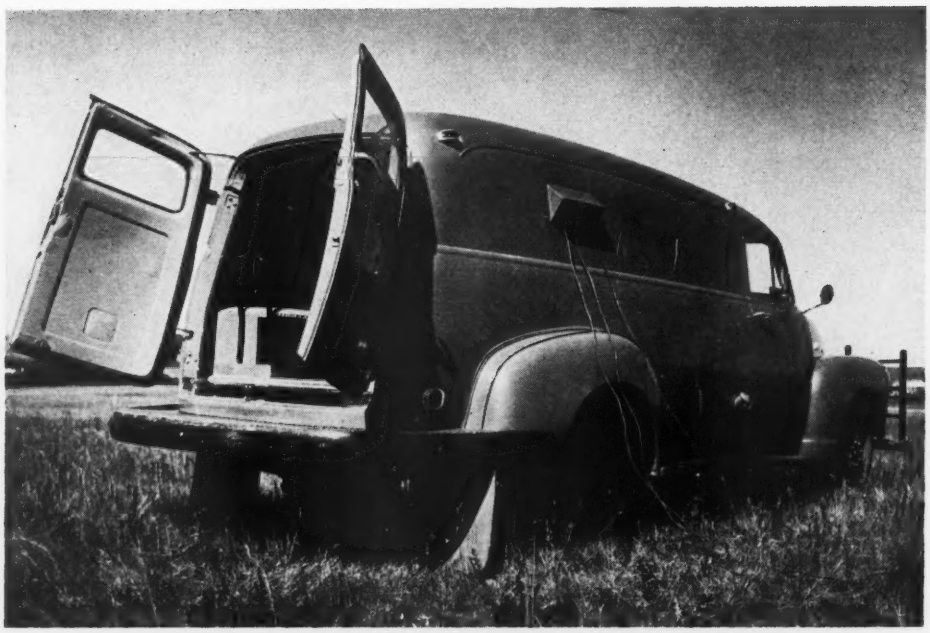


FIG. 3. Seismic recording truck using magnetic tape and amplifiers in a complete unit.

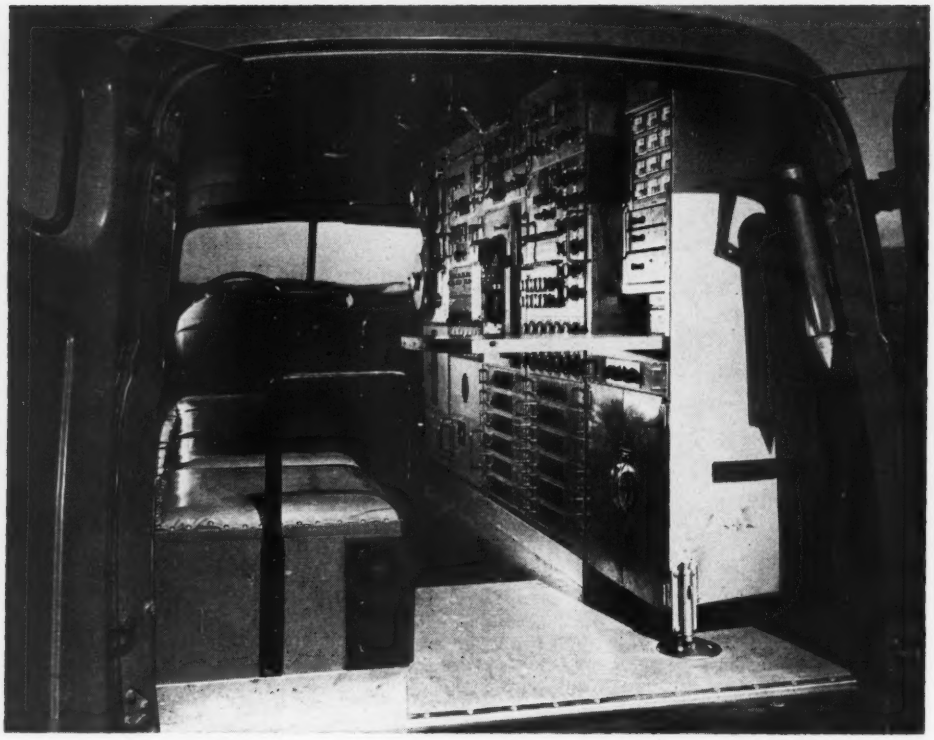


FIG. 4. Interior of magnetic tape recording truck shown in Figure 3.

medium are monitored by an auxiliary recorder which makes a paper seismogram that does not require darkroom facilities. In cold weather a hot water heater and a vented gasoline heater keep the interior warm.

PLAYBACK EQUIPMENT

The playback equipment uses a tape drive mechanism that is practically identical with the recording mechanism. The tape record at each shotpoint is formed into a continuous loop by splicing the end of the record back to a point just ahead of the time break. It is then played back at the original speed of 30 or 15 inches per second, passing repeatedly over the pickup heads. A laboratory-type playback system has been illustrated in a paper by Cortes (1953, pp. 521–522). This type of system requires that all tape records be sent in to the laboratory from magnetic recording units in the field.

Another form of playback equipment, adapted for transportation and intended for use in field offices near the recording areas is illustrated in Figure 5. This reproducer is contained in five boxes as shown; each of these may be encased with wood covers and carried separately to a truck for moving to a new field office. The tape transport with a typical 5-second record in place is shown on the left. The demodulators for converting the FM signals back into the original 12 seismic signals are in the two units below the transport. Time break, uphole, and a time reference signal are also reproduced.

The central unit in Figure 5 contains 12 channels in which there are adjustable high- and low-pass filters. These have closely spaced cutoffs over the seismic band, 12 cutoff points of each type being available. Volume controls, both manual and automatic, are included in the channels so that traces not in trim when recorded can be adjusted for good trim on playback. On the top panel of this unit is a small cathode-ray oscilloscope with which any of the signals from the demodulators may be monitored before application to the playback channels.

The 12 filtered signals are applied to the display unit which is in the box on the right. Here the played-back signals may be visually monitored on the screen of a 5″ cathode-ray oscilloscope. On this screen, which has a long-persistence phosphor, the 12 traces are visible simultaneously. The C-R tube has one electron gun and one beam. Twelve traces are produced by an electronic switch shown on the top panel. On this panel are individual level controls and vertical position controls for each trace. The electronic switch samples each signal about 2,500 times per second. The beam steps from one trace to the next, dwelling on each for about 30 microseconds before going to the next. Although each trace is made up of a series of dots, they are so closely spaced and the traces are scanned so rapidly that the appearance is that of 12 solid traces written simultaneously.

Below the oscilloscope is a timer unit which synchronizes the sweep of the scope with each repetition of the tape loop. Each time a desired portion of the magnetic record passes over the heads the sweep is triggered to show that portion and superposition of successive sweeps is accurate to a fraction of a millisecond.

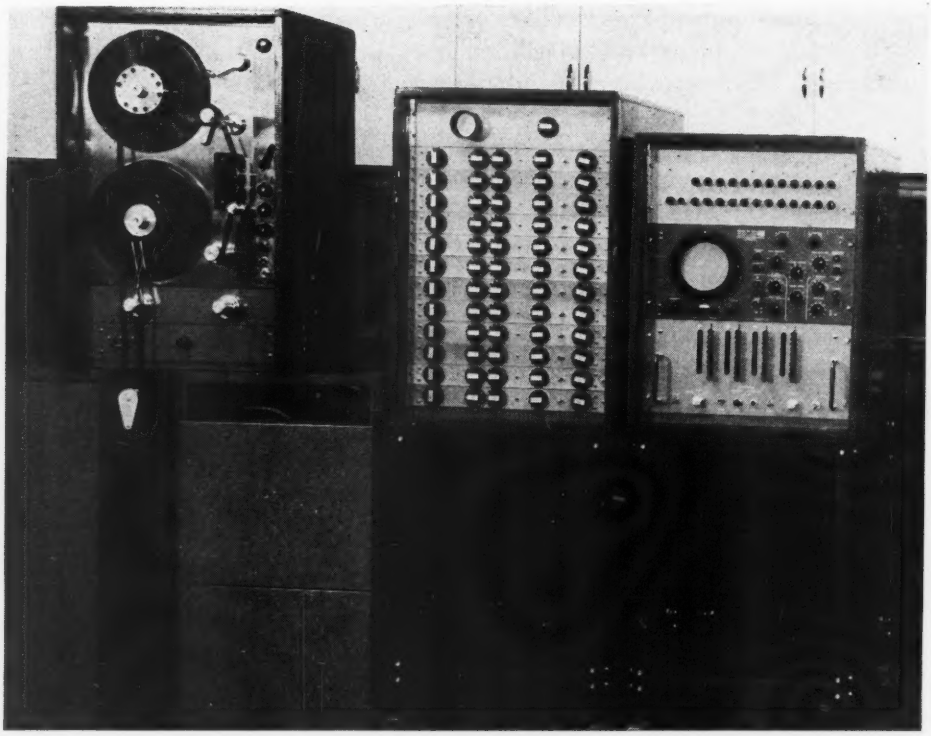


FIG. 5. Portable magnetic tape playback equipment with filter channels and display screen.

There are four sets of push-buttons, from 0 through 9, for selecting the portion of the record to be viewed. These push-buttons represent, from left to right respectively, seconds, tenths, hundredths, and thousandths of seconds. When for example, the dials are set at 1835, the beam begins to sweep at 1.835 seconds after the time break—each time the loop goes around. The sweep speed may be varied at will. If the push-buttons are set on zero and a slow sweep used the entire record may be compressed to show on the 5-inch screen. On the other hand, if the push-buttons are set, for example, on 1.000 seconds and a rapid sweep used, the portion of record visible may be from 1.000 second to 1.050 seconds. Normally, however, the sweep speed is set so that the visible portion of the record has the appearance of a conventional seismogram. It is also possible for the cathode-ray beam to be blanked out for a very short instant at 1/10 second intervals. This effectively puts vertical lines across all traces to serve as a guide to picking record times. These markers stand still as the record is shifted to the right or left so that any event may be placed under a marker and its time then observed on the push-buttons.

The signals from the playback channels, as observed on the display oscilloscope, are also delivered to a recording oscillograph of conventional type where a

standard paper seismogram is made of the modified record. A mixer of a common type is used in combination with the galvanometers and a set of T-pads in the galvanometer circuits, to yield a record showing both mixed and unmixed versions of the played-back profile. Neither of these standard devices is shown in Figure 5. The timing lines on the new paper seismograms are made by glow tubes flashing in step with pulses from the timer unit, which in turn is controlled by the time reference track on the magnetic tape.

EXAMPLES OF PLAYBACK RECORDS

Seismic records made with magnetic tape are shown in Figure 6. The upper record, Record A, is an unmodified playback of a broad-band tape record, band width 10–250 cps. The traces are not mixed and the geophones do not overlap on the ground. The record is not of much value in this form because of excessive surface disturbance around 30 cps which prevails in the early part of the record. Record B was made from the same tape, but it was filtered with a band passing 45–80 cps, adjacent traces being mixed about equally in one direction only (that is, mixed doubles). Reflection lineups not at all clear on the broad-band

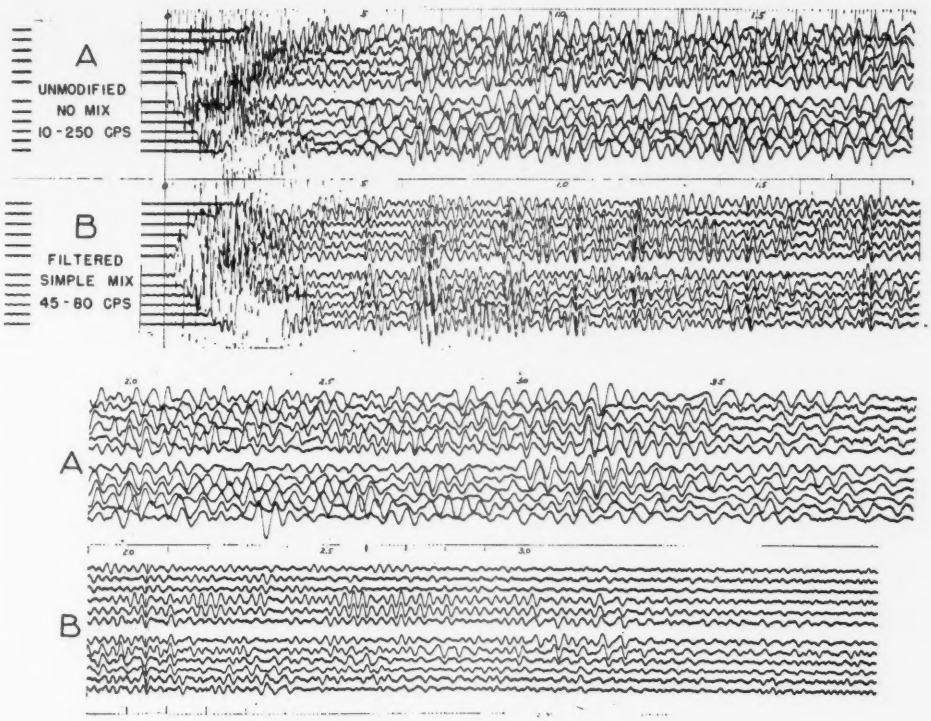


FIG. 6. Removal of surface noise waves with high-pass filtering and simple mixing of a played-back magnetic recording.

record are now distinctly observable. The 30-cycle noise is outside the pass band of Record B and does not interfere seriously. It is also apparent that some of the low frequencies must be included to get any semblance of a reflection lineup late on the record after surface waves have died down. This is true of many seismic profiles. Producing records with a variety of filters and mixes is much more expedient in the office with a reproducible record than attempting to repeat the shot in the field.

Figure 7 shows a seismic record with a broader frequency response. Record A is an unmodified playback of a magnetic tape record. Here the amplifier response is so low in frequency that an AVC or expander sensitivity control was not practical. The sensitivity is fixed at two values, a low value from 0 to .8 second, at which

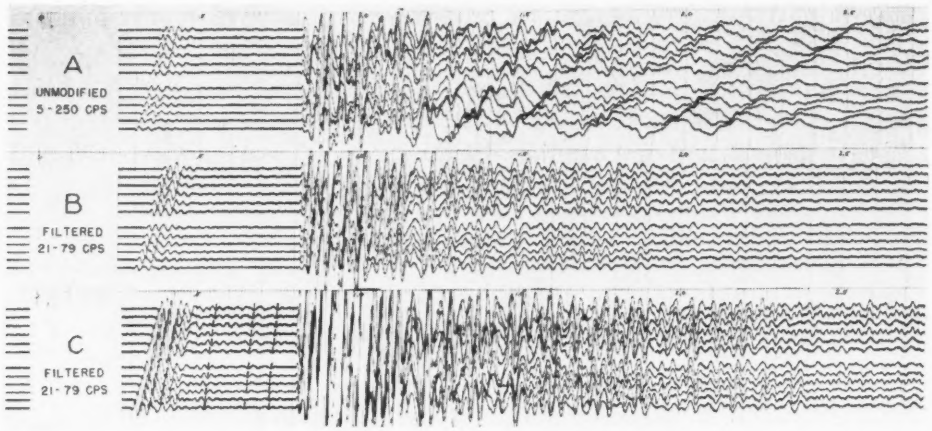


FIG. 7. Reflection record without AGC or expander shows full range of frequencies and amplitudes involved when played back with various filter and amplitude settings.

time it was increased suddenly by a factor of 100. This technique of gain control requires very simple circuitry involving relays. Low-frequency surface waves of about 5 cps are apparent on Record A. Record B shows how these low frequency waves were filtered out on playback, with response limited in the lows to about 20 cps. Here the reflection line-ups are clean, and, because the gain is constant and known, true relative amplitudes of the reflections are measurable from beginning to end. Some early reflections are lost between .5 and .8 second because they are too weak on the paper Record B. The magnetic tape was again played back and Record C produced with higher playback gain. On this record, the early reflections have become apparent and the late reflections have been brought up to more useable amplitude. Further manipulation of the playback settings will enhance any portion of the record that is of particular interest.

The records of Figures 8 and 9 again illustrate how a filter most suitable for one portion of a record may not be best for another portion. The top two records of Figure 8 show two reflection events between 1.6 and 1.7 seconds that are

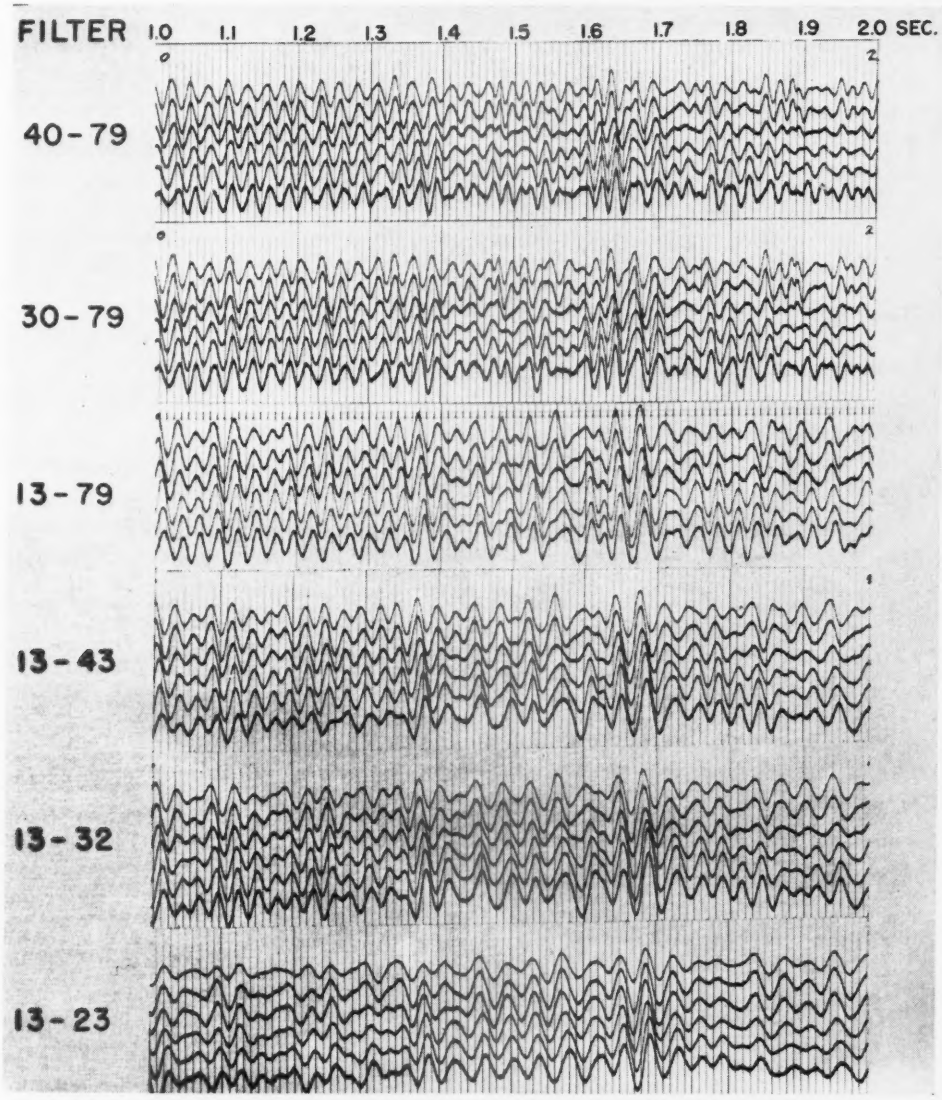


FIG. 8. Separation of some events and loss of separation of others are indicated as frequency of pass-band is lowered in the playing back of a single magnetic recording.

distinctly separated with a filter which passes some high frequencies and excludes extreme lows. As lows are allowed to pass, however, and also as highs are suppressed, the two events merge and resolution is lost as evidenced by the bottom records. At the same time, however, the events between 1.0 and 1.4 seconds are improved, as observed by comparing the legginess of the high-frequency record at the top with the lower frequency record, where a filter 13–32 cps permits

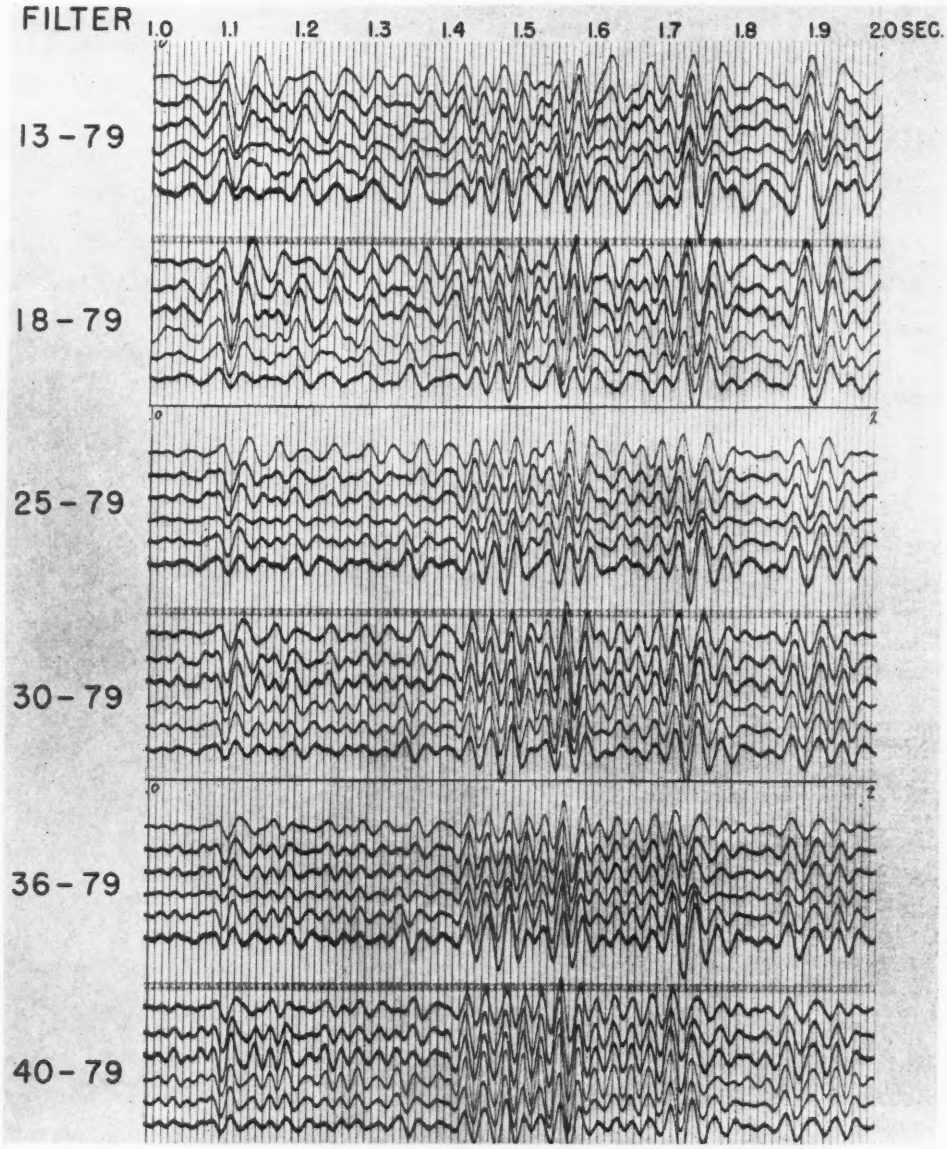


FIG. 9. Loss of reflection character and standout is indicated as the pass-band is narrowed toward higher frequencies.

much better discrimination of events. These records were all made by repeated playing back of one magnetic tape record.

In Figure 9 are records illustrating a case in which the use of a relatively broad band of frequencies actually produces a better standout of events than is obtained when the low frequencies are excluded. The broad band records at the

top show good standout of separate events between 1.4 and 2 seconds whereas the three records nearest the bottom which were made with high frequencies are quite leggy.

The profiles represented in Figures 8 and 9 are from widely separated shot points on the same prospect. It would be too much to expect one or two instrumental settings to yield optimum data over the whole prospect area. It was found that even on some single profiles the best filter setting for a deep shot would be distinctly different from the best setting for shallower shots.

USEFULNESS OF MAGNETIC RECORDING

All these records are presented to illustrate that broad band magnetic recording provides considerably more information per seismic shot than is obtained when only a paper record is made, with filters, in the field. In areas where shot hole conditions are such that more than one shot at the desired depth may not be obtainable, or where complex shot patterns are in use, the ability to produce seismograms with various filters and mixes by playback of a single reproducible record is especially advantageous. An additional advantage is that the records are preserved in a form which will permit their use many years later in the event that new analytical techniques are developed. For example, the recent development of high speed computing equipment opens up new possibilities for analytical procedures which may be readily applied to seismic data. If the seismograms are in reproducible form they are more suitable for reading by such computers.

Although the equipment described was assembled for experimental investigations of the seismic method, it is concluded that magnetic recording, when properly engineered for the job, should eventually be used on a wide scale in the routine application of exploration seismograph.

REFERENCES

Cortes, H. C., 1953, Geophysical progress: Geophysics, v. 18, p. 510–524.

Jakosky, J. Jay and Jakosky, John J., Jr., 1952, Frequency analysis of seismic waves: Geophysics, v. 17, p. 721–738.

THE GULF AIRBORNE MAGNETIC GRADIOMETER*

W. E. WICKERHAM†

ABSTRACT

An instrument capable of measuring magnetic gradients as encountered in airborne magnetometer operations has possible applications as an interpretational aid. Its usefulness, particularly for qualitative analysis, will be discussed briefly. The design of a spatial-type airborne gradiometer of adequate precision can be shown to be quite impractical. An instrument based on the time derivative of the magnetic intensity variations provides a useful alternative and is described.

INTRODUCTION

The purpose of this paper is to describe an instrument which is capable of producing a continuous record of magnetic gradients as encountered in airborne magnetometer operations. The apparatus will record continuously the rate of change of the total magnetic intensity of the earth's field along the line of flight. These data may be of considerable assistance in the interpretation of the total intensity records when both are observed simultaneously. This is especially true where magnetic anomalies of considerable magnitude are encountered, as in the case of mining work where there are shallow igneous rocks and sharp anomalies. On the other hand, gradient records are less pertinent in the case of the smoother magnetic features associated with the deeper basements in areas where petroleum exploration is carried on.

Before describing the apparatus, let us consider one type of anomaly encountered in mining work where even a qualitative analysis of data may in itself justify our recording the gradient simultaneously with the total intensity.

MINING GEOLOGY AND MAGNETIC DATA

It is well known that many valuable mineral deposits are often very closely associated with intrusive igneous rock masses. An example of such an intrusive is shown in Figure 1. It might represent the cross-section of a serpentine plug, an elongated dike or similar feature. Such intrusives are likely to be very close to the earth's surface, and while mineralization may occur in various configurations, the edges of the mass are often of particular interest. For our purposes, we shall consider that mineralization occurs at the sharp edges, as shown.

Now, neglecting mineralization effects, a magnetic intensity record across a vertical intrusive of relatively high magnetic susceptibility will reach a maximum at the center of the intrusive. The inflection points of this curve lie close to the boundaries of the mass, defining width d.

* Presented at the Annual Meeting of the Society at Los Angeles March 26, 1952. Manuscript received by the Editor June 8, 1953.

† Gulf Research & Development Company, Pittsburgh, Penna.

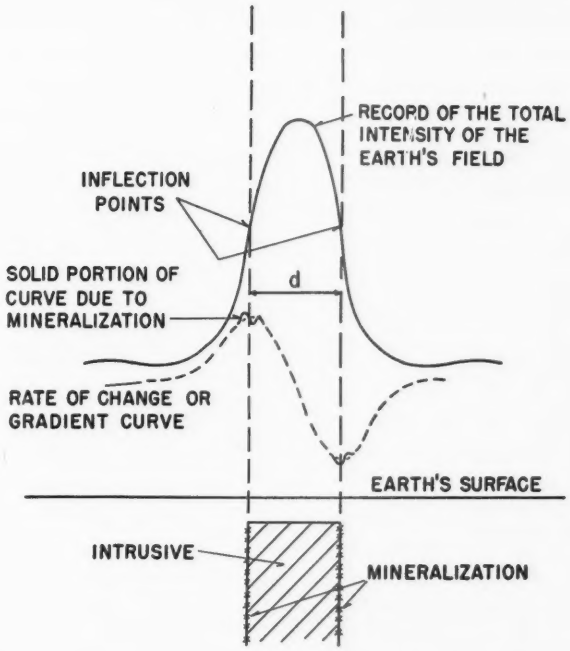


FIG. 1. Magnetic profiles associated with an idealized intrusive igneous rock mass.

A record of the rate of change of intensity, as shown by the dotted line, shows that d is equal to the distance between the crests of this curve.

It is obvious that the rate curve provides a simplified method for establishing d. Further, it is conceivable that for a typical anomaly, where the intensity curve is not so easily defined, the rate curve would prove even more useful.

Let us proceed to the case where a narrow zone of magnetic mineralization exists at the sharp contacts. Since the zone of mineralization may be relatively narrow and perhaps rather weakly magnetic, it will be evident that the intensity change associated with this zone would necessarily be small. Moreover, the susceptibility contrast between the mineralized zone and igneous intrusive is not nearly so pronounced as it would be in ordinary surroundings. Furthermore, the anomaly caused by the mineralized zone occurs at the most unfavorable time: namely, when the slope of the intensity curve due to the intrusive is at its steepest point.

The total intensity record of an anomaly of the type described may show a deviation of several thousand gamma due to the intrusive, while superposed on this curve near the inflection points are the small anomalies due to mineralization. Now, if the sensitivity of the system is adjusted so that the entire intensity curve is recorded on a reasonable width of paper, the contact anomaly is not discernible. The alternative of increasing the sensitivity and recording small increments of the total intensity also has its difficulties, which will now be considered.

Suppose that the full scale sensitivity of the recording device is adjusted to record small increments of the large anomaly and that automatic means for stepping the recorder back on scale are provided. Offhand, one might expect to be able to identify readily a mineralization contact with such high sensitivity. However, upon further examination, it will be evident that in order for the recorder to follow the large anomaly related to the intrusive itself, the recorder pen is rapidly urged to the end of the scale, a step is cranked in to bring it back on scale, and it again travels rapidly across the chart, etc. The net effect then is that the small superposed anomaly is stretched out, thus making it difficult to detect, or it may be totally obliterated by the pen-stepping process.

A gradiometer record, on the other hand, will show a small anomaly superposed on a large one, as in Figure 1.

This example, while idealized, is none the less representative of the problem encountered in mining surveys and illustrative of the usefulness of gradiometer records. Their value in qualitative measurements and correlation problems will be readily recognized. Quantitative measurements are possible, but the means for accomplishing this will be considered later. Thus far, we have attempted only to show the basic purposes of the instrument.

INSTRUMENTAL CONSIDERATIONS: SPATIAL-TYPE GRADIOMETER

Two magnetometers spaced some distance apart and each measuring the intensity of the earth's field would comprise a magnetic gradiometer. The readings might be combined directly and the difference exhibited on a single record as the magnetic gradient. However, it is not difficult to show that an instrument of this type is quite impractical for airborne operations.

A moderately high magnetic gradient in the earth's field might be on the order of 6,000 gamma per mile. Now suppose that the gradient is linear and that two magnetic detectors are spaced six feet apart to measure the difference in field intensity over that distance. At 6,000 gamma per mile, the change per foot would be 1.14 gamma or a total of 6.8 gamma for six feet. The gradient considered represents one of considerable magnitude from the standpoint of practical operations and hence, 10 gamma should be exhibited as nearly a full-scale deflection of the recorder. These sensitivity requirements are excessive for a fast response system having small time lags and practically no attenuation.

Moreover, the requirements for alignment of one element with respect to the other are intolerably high. If operated in the most favorable position, namely, parallel to the total vector, the total ambient field observed by each element may be of the order of 50,000 gamma. Then, from an orientation standpoint, a misalignment of 1 gamma represents

$$\cos^{-1}\theta = .99998$$

or $\theta = 1/3°$. Hence a transient misorientation of one element axis with respect to the other of $1/3°$ would be recorded as a very significant apparent anomaly.

These considerations do not mean that flux-gate gradiometers comprising spaced elements, i.e., spatial-type gradiometers, are impractical for all purposes, but they do show quite conclusively that they are not suitable for normal airborne use. Indeed, there are other even more convicing reasons for discouragement in the design of such a device but instrumental details are involved that do not warrant discussion here.

TIME-DERIVATIVE GRADIOMETER

It will be recalled that the airborne magnetometer for measuring total intensity is a continuously recording instrument. Moreover, the Gulf instrument has a sufficiently fast response to follow faithfully very rapid changes in intensity. It is therefore possible to take the time-derivative of the recorded intensity as representative of the time rate of change of the magnetic variations traversed. Since the aircraft is traveling in a substantially straight line and at a known and relatively constant ground-speed, it will be evident that the time-derivative record may be converted directly into a gradient record by merely converting time into distance—the aircraft ground-speed being known. However, there appears to be no very forceful reason for converting the time-derivative curve to a gradient curve since the two records would be identical, except for the scale factor, for a given aircraft speed. Certainly for qualitative interpretation purposes the time-derivative curve needs no modification and can be treated as equivalent to a gradient curve.

This apparent equivalence of the time derivative and true magnetic gradient curves in the case of airborne operations provides the means to circumvent the serious instrumental problems of the spatial-type gradiometer already mentioned. We may therefore proceed to outline the principles of the airborne magnetic gradiometer.

THE GULF AIRBORNE GRADIOMETER

The Gulf Airborne Gradiometer is essentially an attachment used in conjunction with a standard Gulf Airborne Magnetometer.

Figure 2 shows a partial block diagram of the magnetic-measuring circuit with the orientation features omitted in the interest of simplicity.

In Figure 2, the output of a 400-cycle source excites a fluxgate detector element. When any fluxgate element is driven hard enough to saturate its highly permeable core, the time at which saturation occurs is dependent upon the magnitude of the ambient magnetic field. The output of a fluxgate can be in the form of sharp pulses whose relative positive and negative amplitudes are indicative of the magnitude of the ambient field. Thus, when the positive and negative output pulses are equal in amplitude, the element is in zero ambient field.

Now, the detector element operates in the total earth's field, so that without auxiliary means for equalizing the pulses, one pulse would be very large and the other one very small. However, by passing dc current of proper polarity through

the secondary coil encompassing the element, an artificial field is created which can be made exactly equal and opposite to the ambient earth's field, in which case the pulses would be equal in size. This immediately suggests a null system of measurement which is highly desirable.

Referring again to Figure 2, the circuit involves a differential detector which recognizes the difference in positive and negative pulse amplitudes. Additional components serve to produce a voltage suitable for running a motor whenever the pulses are unequal in amplitude. The motor drives a potentiometer which

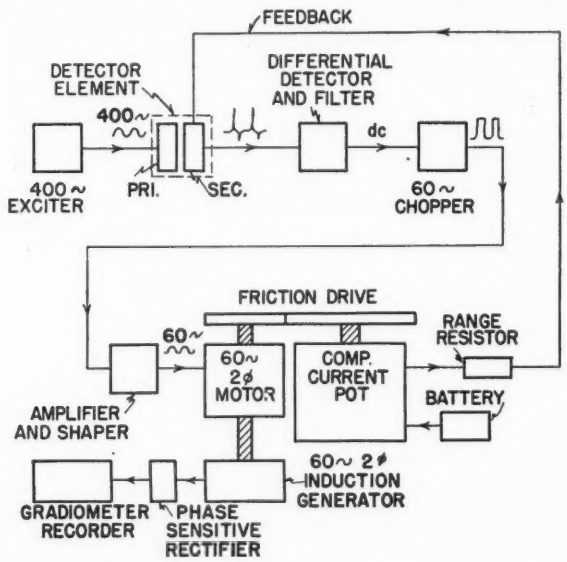


FIG. 2. Block diagram of the Gulf airborne magnetometer system.

controls the dc current through the compensating coil of the detector element. Since the compensating current is that which exactly nullifies the earth's field, a measurement of this current constitutes a measurement of the earth's field. This is accomplished by a potentiometric measurement of the voltage drop across a range resistor of proper size.

It has been shown that a motor runs whenever there is some change in the intensity of the earth's field, and stops when the compensating current has been readjusted to accomplish null conditions. Clearly, the direction of rotation of the motor depends upon the direction of the change in the earth's field.

Now, a two-phase induction-type generator is coupled to the motor shaft. The output of this induction generator depends in phase and amplitude upon its direction of rotation and angular velocity. A phase sensitive rectifier is used to convert this voltage into dc whose polarity and magnitude is also proportional to the direction and velocity of the generator's rotation. It follows that the variations in dc output voltage are directly related to the rate at which compensating

current is being changed; hence, the voltage appears as a derivative of the recorded magnetic field intensity.

A second potentiometric recorder is used to measure a portion of the derived dc voltage and by selection of appropriate taps on a voltage divider, different sensitivities may be attained on the recorder chart.

Once again it is emphasized that in recording the generator's output, we are recording the time rate of change in the earth's field and, in effect, recording the same quantity that a conventional gradiometer would record except for the ground-speed factor, which is adequately known and may be applied if desired. We have, however, circumvented the instrumental problems involved in the conventional type gradiometer and obtained more than adequate sensitivity.

QUANTITATIVE MEASUREMENTS

As far as we know, no serious attempt has been made to apply a quantitative interpretation on gradiometer records. However, the instrument has been calibrated so that quantitative studies may eventually be made. This has been accomplished by providing curves which show the rate of change for a given recorder deflection as in Figure 3.

The deflection from center scale of the recorder at any time indicates a certain rate of change which may be read from the curves. These data are readily converted to gradients. For example, a linear change of 6,000 gamma per mile at 140

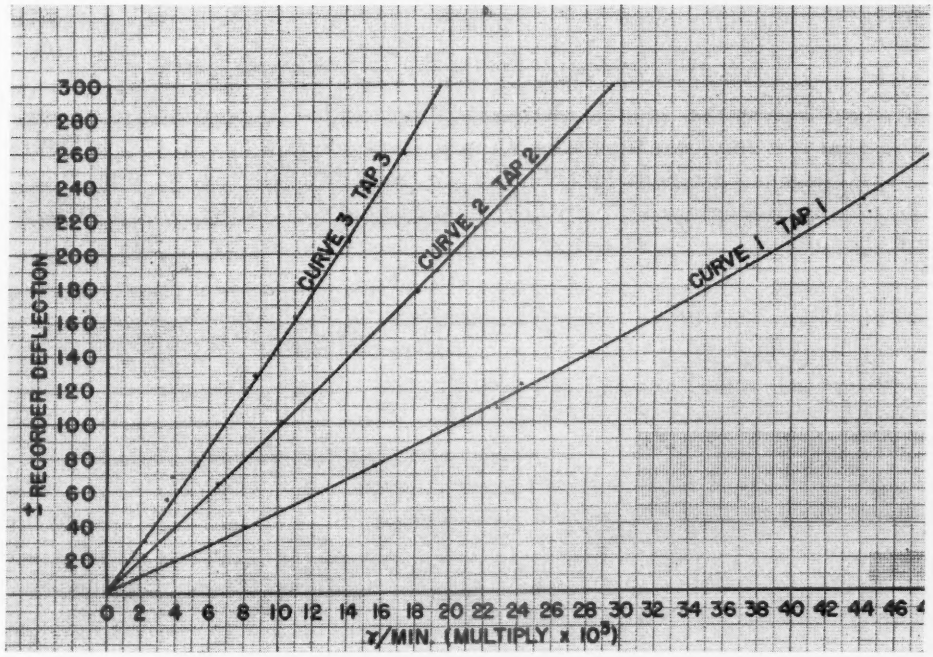


FIG. 3. Calibration curves of gradiometer.

miles per hour would give a rate of 14,000 gamma per minute. With the instrument connected so that curve no. 3 applies, this rate would cause the recorder to deflect 208 divisions (± 300 divisions is full scale). Conversely, if the recorder deflection observed was 208 divisions, the rate of change at that instant would be 14,000 gamma per minute, which at 140 miles per hour represents a gradient of 6,000 gamma per mile.

EXPERIMENTAL RECORDS

In order to demonstrate the effectiveness of the gradiometer for correlation and qualitative studies, an anomaly was simulated in the laboratory. A large magnet was rotated at a given speed to simulate a large anomaly caused by an intrusive. Simultaneously, a small magnet was rotated at a faster rate to simulate a contact anomaly.

Figure 4 shows the intensity recording of the small magnet rotating alone, while Figure 5 shows the intensity record with both magnets rotating. The sen-

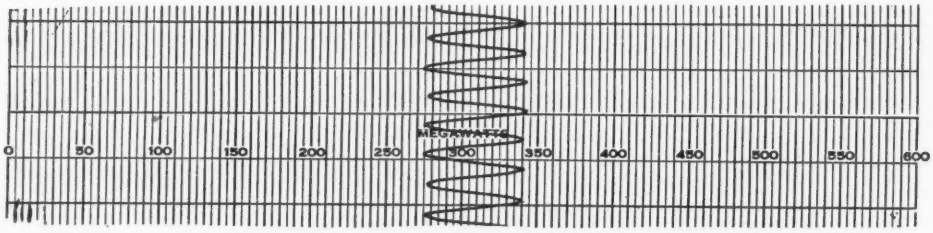


FIG. 4. Total intensity record obtained by rotating a small magnet.

sitivity is high so that small deviations will be recorded, as previously discussed. Note that it is only near the peaks of the wave at points 1, 2, 3, 4, and 5 (Figure 5) that the small magnet's contribution can be readily detected. At other times, the recorder is moving so rapidly and stepping so often that the small deviations are obscured.

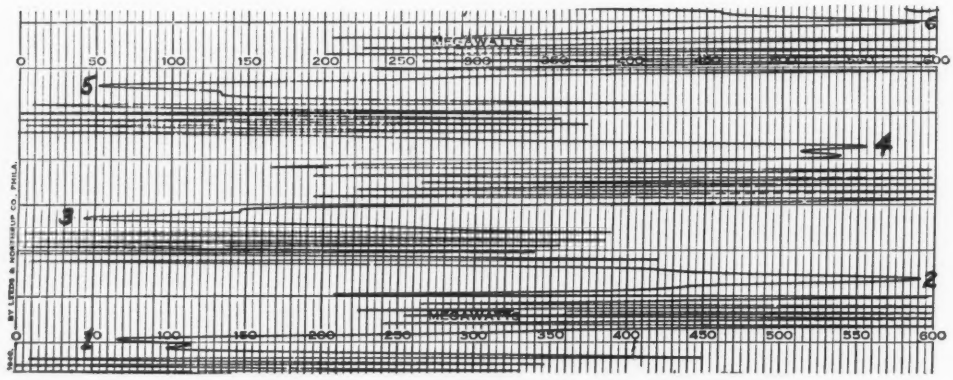


FIG. 5. Total intensity record obtained by rotating a large and small magnet simultaneously.

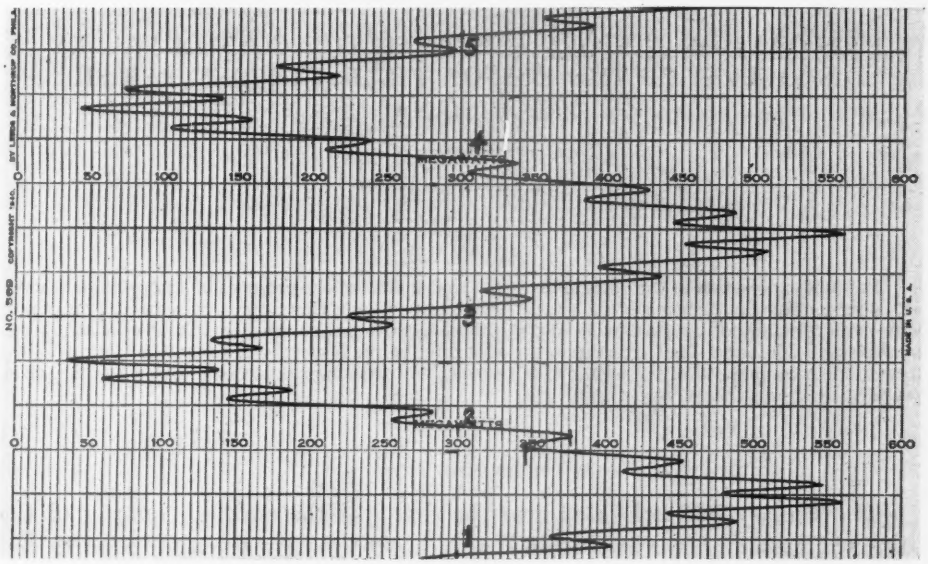


FIG. 6. Rate-of-change record of the total intensity record shown in Figure 5.

Now Figure 6 shows the gradiometer record of the same setup. The rate of change of the large anomaly is not great enough to cause the record to exceed scale length and the small excursions superposed on the large variation are due to the small rotating magnet and are readily apparent.

ACKNOWLEDGMENT

The writer expresses thanks to the Gulf Research & Development Company for permission to publish this paper. He is also indebted to Mr. R. D. Wyckoff for valuable advice and to Mr. O. K. Doolen, who collaborated in the development of the equipment.

EXPLORATION HISTORY (PRIOR TO THE COTTON VALLEY DISCOVERY) OF THE RUSTON FIELD, LINCOLN PARISH, LOUISIANA*

J. RYAN WALKER†

ABSTRACT

The first exploration in the Ruston field area that indicated the presence of a structural feature was a reconnaissance surface survey by the Arkansas-Louisiana Gas Company in 1931. This paper, with maps, describes the surface work and the subsequent reflection seismograph surveys conducted by Arkansas-Louisiana Gas Company in the area prior to the discovery of gas in the Cotton Valley formation. A comparison of the results of the surface and seismic work is made with the structure as revealed by present subsurface control.

INTRODUCTION

The Ruston field is located near the center of the northern quarter of the state of Louisiana. It is in Lincoln Parish, approximately seven miles north and slightly east of the town of Ruston. Geologically, it is located just outside the northeastern limits of the North Louisiana salt dome basin. The terrain of the area is rather heavily wooded, and is more rugged than it is rolling. The surface elevation varies from 100 feet to 343 feet, and the principal drainage is by Cypress and Colvin Creeks. The structure, which in all probability has resulted from salt movement at great depth, is rather symmetrical in shape, with a slight elongation along its north-south axis. The relationship of the Ruston Field to other fields, of greater or lesser importance, in the surrounding territory may be seen in Figure 1.

The discovery well, the Arkansas-Louisiana Gas Company No. 1 Jiles, was drilled after a reconnaissance surface survey, two reflection seismograph surveys, and an unsuccessful test. This well was completed in 1943, in a gas sand of the upper Hosston (Travis Peak) formation. Subsequent drilling established gas production in lower Glen Rose sands. A later seismograph survey was made to determine the structural development of the Cotton Valley formation. The discovery of gas in that formation resulted from the Crescent Drilling Company No. 1 C. M. Matthews test in 1948. Later development established gas-condensate production in the "D," the Bodcau, and the Vaughn members of the upper Cotton Valley sand series. In the course of the present development a geological section has been explored that extends from the upper Claiborne group of Eocene age at the surface to the upper Cotton Valley sands of Jurassic age.

* Presented at Sixth Annual Midwestern Meeting, Fort Worth, November 13, 1952. Manuscript received by the Editor September 17, 1953.

† Arkansas Natural Gas Corporation, Shreveport, Louisiana; with Arkansas Fuel Oil Corporation, Shreveport, Louisiana since separation and reorganization of Arkansas Natural Companies, April, 1953.

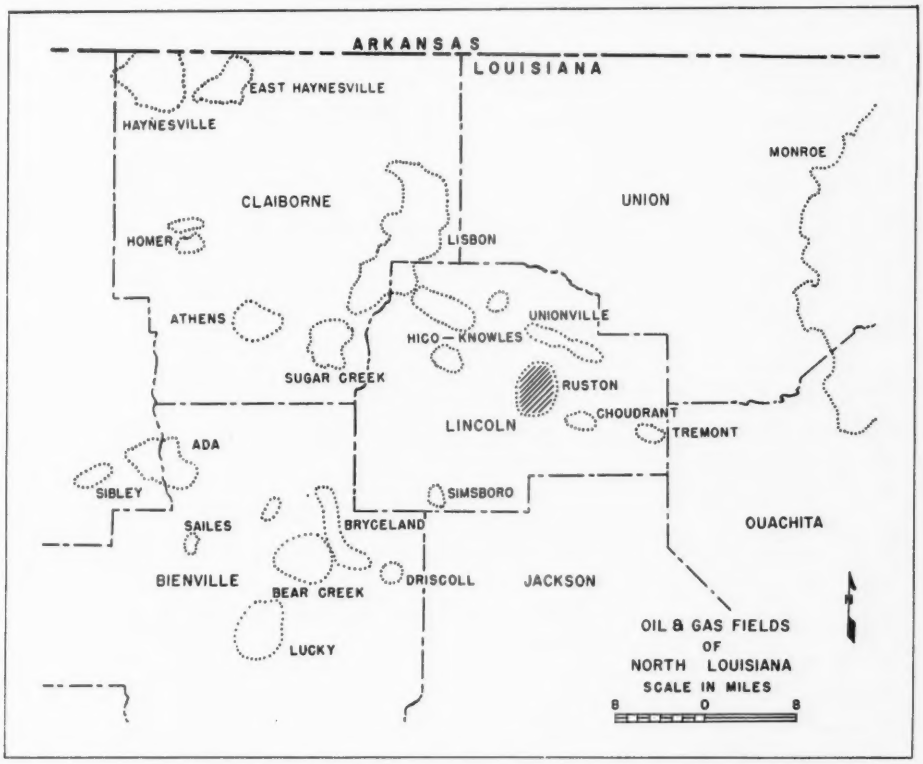


FIG. 1. Map of portion of northern Louisiana showing location of Ruston field.

SURFACE SURVEY

Late in 1930, a reconnaissance surface survey, was started by Mr. A. E. Oldham of the Arkansas-Louisiana Gas Company in an area covering several townships north of the town of Ruston. Elevations were mapped on what was referred to at that time as the top of the Minden beds. This marker may be identified as the upper glauconitic sand member of the Cook Mountain formation. From this survey, which was completed early in 1931, Mr. Oldham mapped a surface structure (Figure 2) which centered approximately two miles east of the southwest corner of T-19N, R-2W. On the basis of this significant surface anomaly, the Arkansas-Louisiana Gas Company acquired leases totaling approximately 8,500 acres.

SEISMOGRAPH SURVEY—1934

As one of its first assignments, the Arkansas-Louisiana Gas Company's first seismograph party started a reflection survey in this area in May, 1934. A correlation method was employed using five geophones spaced at 200 ft intervals on 1,800 ft to 2,600 ft spreads. It might be well to mention here that these geophones were many times larger and heavier than the geophones used today. The task of

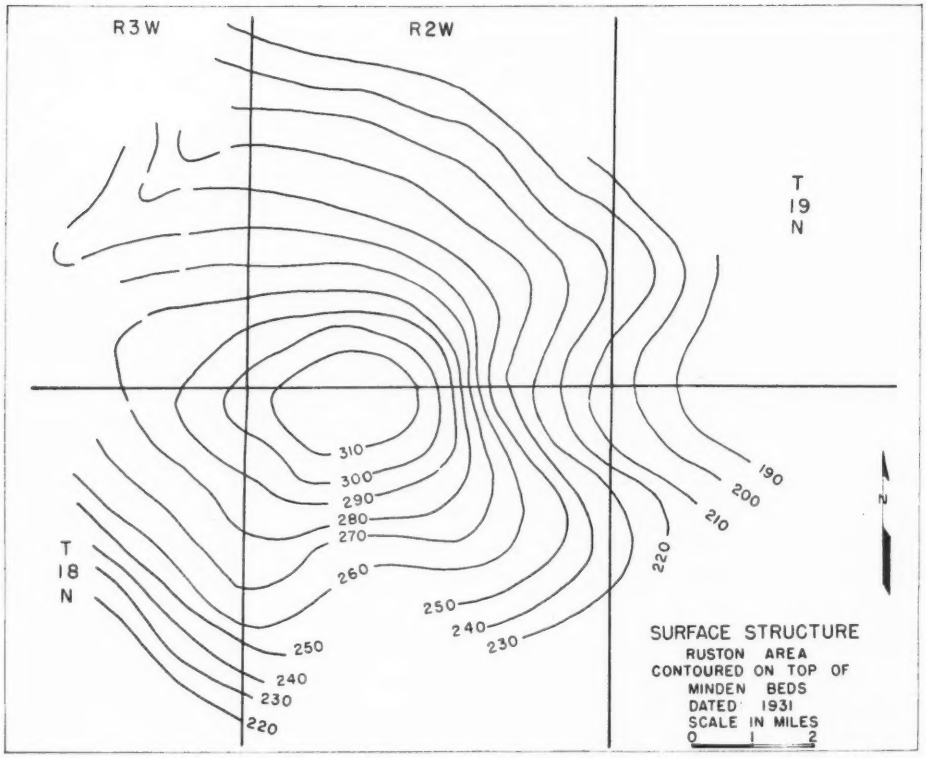


FIG. 2. Surface structure on top of Minden beds (upper glauconitic sand member of Cook Mountain formation).

laying out several hundred feet of heavy, rubber-covered shielded cable while carrying from two to four geophones plus a hand auger and other equipment was usually assigned to men well endowed with energy and determination.

The recording for this survey was done in a "leap-frog" manner along available roads and trails. Hand-dug holes were used, and an average of two to three shots were made in each hole at an average charge depth of 18 feet. The average charge was less than $\frac{1}{2}$ pound of dynamite. All recordings were made with a single oil-damped geophone for each trace, and there was, of course, no elaborate frequency control, mixing, or automatic gain control, because at that time such developments in instrumentation had not yet come into field use.

Weathering records were taken, and corrections were made by averaging the zero intercepts of the time-distance curves. A weathering velocity of 2,000 feet per second was used.

The apparent reflections were marked, and the deepest ones considered correlative to the entire area were assumed to correspond to the base of the Ferry Lake anhydrite. A velocity of 7,700 feet per second was applied to determine

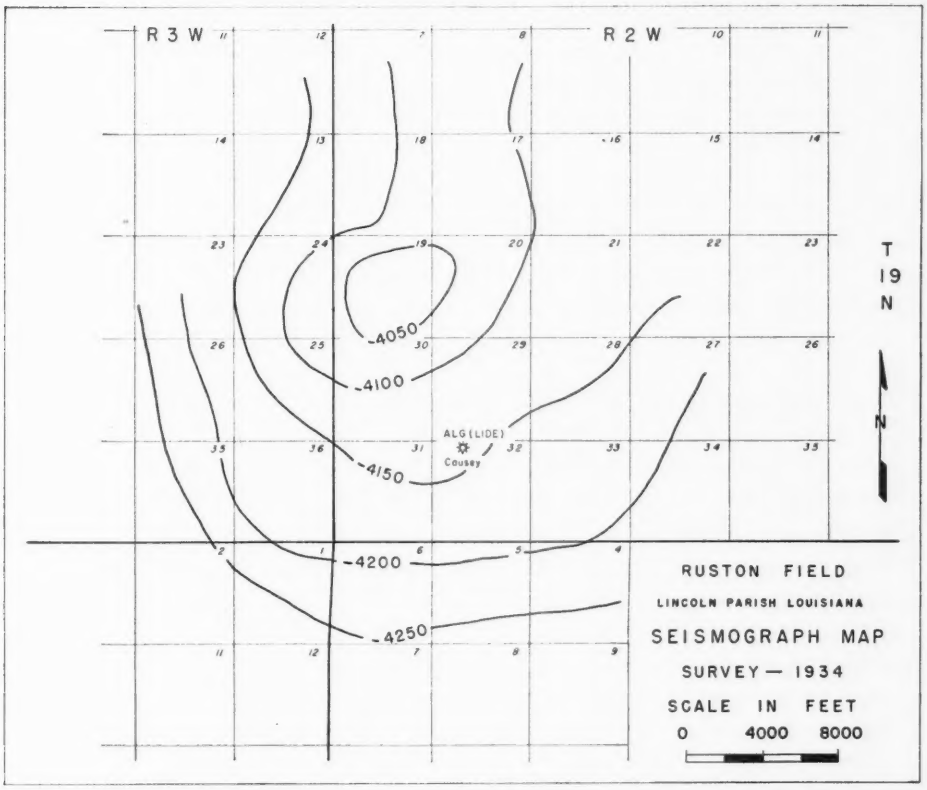


FIG. 3. Reflection seismograph map showing contours on base of Ferry Lake anhydrite.

depths to that horizon. The survey was completed in June, 1934.

An interpretation representing the configuration of what was assumed to be the base of the Ferry Lake Anhydrite may be seen in Figure 3. Data obtained in the northern part of the area indicate that the single closure centering in section 19 could have been supported by an additional 50 feet of closure to the north. Either because of the lack of permits or because of inaccessible terrain, the control in the area immediately north of the single closure was rather loose. It appears, however, that the interpreter did not elect to take advantage of this uncertainty and present a more optimistic delineation of the structure.

Figure 4 shows a comparison of the surface structure mapped from the 1931 surface survey with the one indicated by the first seismic interpretation. Here may be seen a divergence of some three miles between the "highs" indicated by the two methods. It is obvious that this disagreement in structural relationship could have created an annoying problem as to where to locate the initial test. This would have been especially likely if the geologist and geophysicist were each convinced that his interpretation was reasonably accurate.

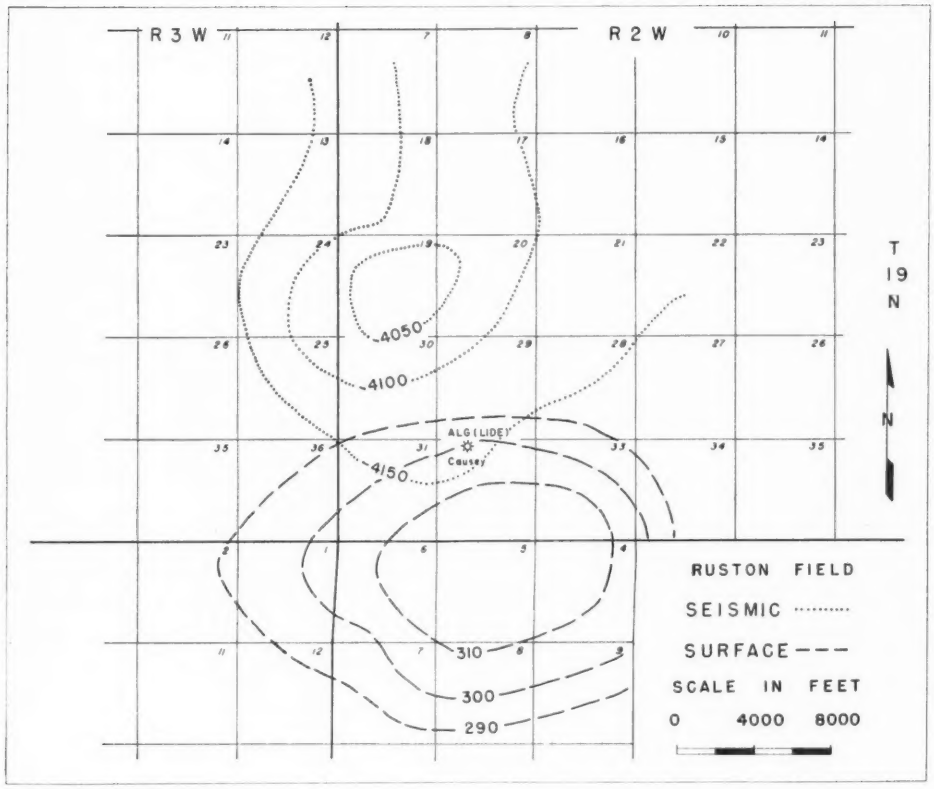


FIG. 4. Comparison of surface structure on top of Minden beds with seismic structure on top of Ferry Lake anhydrite.

THE INITIAL TEST

Another seismograph survey was made of the area by the same company early in 1936. Its purpose, of course, was to clarify the disagreement between the surface and seismic interpretations, but it was not completed in sufficient time to have any bearing on the location of the initial test.

By current standards it seems logical that the first location should have been made on one structural high or the other, unless, of course, a drilling obligation had to be fulfilled to hold what appeared to be an important but less favorably located lease. However, a compromise was made and it was placed approximately half way between the two anomalies.

This test, the Arkansas-Louisiana Gas Company No. 1 Causey was drilled in the NE¼ of the NW¼ of section 32, T-19N, R-2W, to a depth of 4,687 feet and was dry and abandoned on April 19, 1936. It was later taken over by Lide et al. and was deepened to 5,822 feet. It was completed on September 5, 1937, through perforations from 5,316 ft–5,322 ft for 32,700,000 cubic feet of gas and a con-

siderable amount of salt water per day. The producing sand was near the base of the Pine Island shale, approximately 50 feet above the top of the Sligo formation. It was not a clean completion because of the large salt water flow, and gas company operators refused to take the gas into their lines. Although it was eventually put on a local line and produced some gas, it was not a commercial well because of the lack of success in controlling the salt water flow. After being reworked a number of times it was finally abandoned in 1948. Future development proved the producing sand to be very lenticular and poorly developed. Because of this, and the fact that no other well in the field has produced from the Causey sand, this initial test is not considered the discovery well.

SEISMOGRAPH SURVEY—1936

The instruments used in the 1936 seismic survey were of different design from those used in the 1934 survey. In recording, an "expander" was used to control the energy amplitude on the records. The field technique differed in that spreads giving much shorter ground coverage were placed considerably closer to the shot points. Five geophones were used on 1,400 ft to 1,800 ft spreads. The shot holes

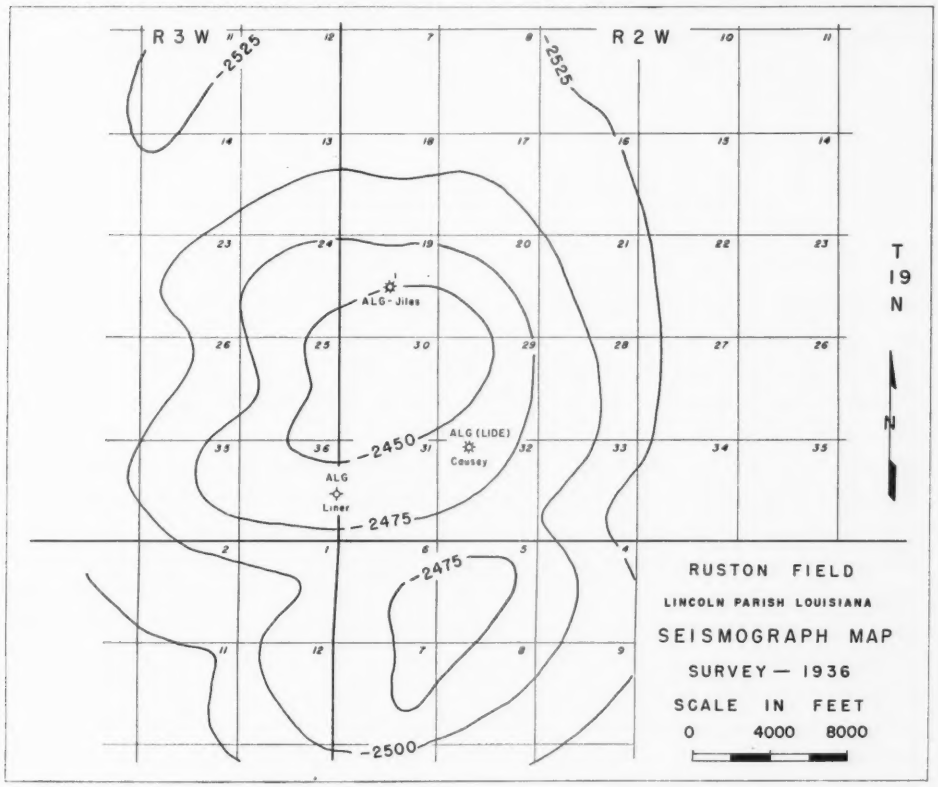


FIG. 5. Reflection seismograph map showing contours on the Annona chalk.

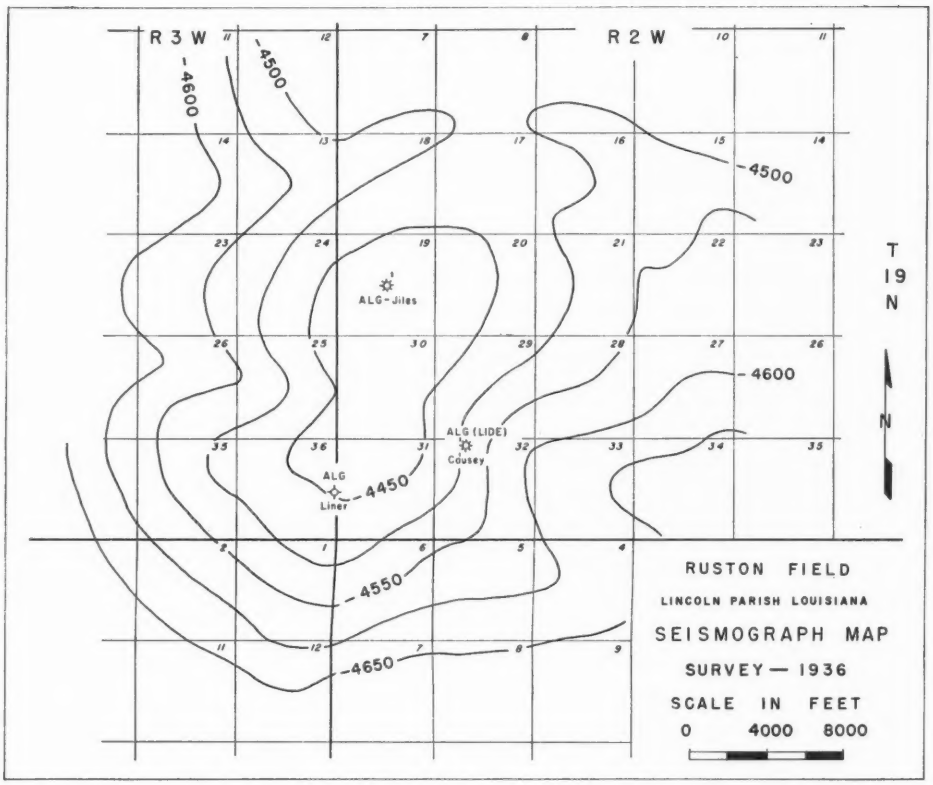


FIG. 6. Reflection seismograph map showing contours on top of the James limestone.

were drilled by the use of a mechanized hand auger with a small air-cooled engine furnishing the rotary power.

The records obtained by this correlation technique looked better than those obtained from the earlier survey, but it seems that appearance might have been misleading, at least to some extent. Interpretations were made on what was believed to be the Annona chalk and the James limestone. Future development showed that both interpretations were in fair agreement with subsurface control for the northern half of the area but were in considerable disagreement with the subsurface for the southern half. Figure 5 shows a seismic interpretation from this survey on what was believed to be the Annona chalk. Here two separate closures are shown instead of the one indicated on the deeper Ferry Lake anhydrite interpretation (Figure 3) from the earlier survey. The closure to the south on the Annona Chalk map represents a somewhat closer agreement with the surface structure (Figure 2). Although a subsurface map of the Annona chalk was not prepared for this paper, it does place the high points on that horizon in section 30, T-19N, R-2W, indicating some southward shifting of the shallower beds. An interpretation representing the configuration of what was assumed to be the

top of the James may be seen in Figure 6. The structural feature here is considerably more elongated to the south as related to the Ferry Lake anhydrite interpretation, but without two separate closures as indicated on the Annona chalk map.

THE DISCOVERY WELL

It was a number of years after the completion of the Lide et al. No. 1 Causey before another test was drilled. The lack of success with the Causey well might have discouraged further operations; however, the lack of interest can be attributed largely to inadequate pipe line facilities to make possible a favorable market for gas in the North Louisiana area.

By the time interest in further testing was renewed, the expiration dates of many of the original leases in the Arkansas-Louisiana Gas Company's block were drawing to a close. However, by 1943, they had reassembled a sizeable block of acreage.

Acting on information from the early seismic surveys, the company located the F. W. Jiles No. 1 in section 19, T-19N, R-2W. It was completed on October

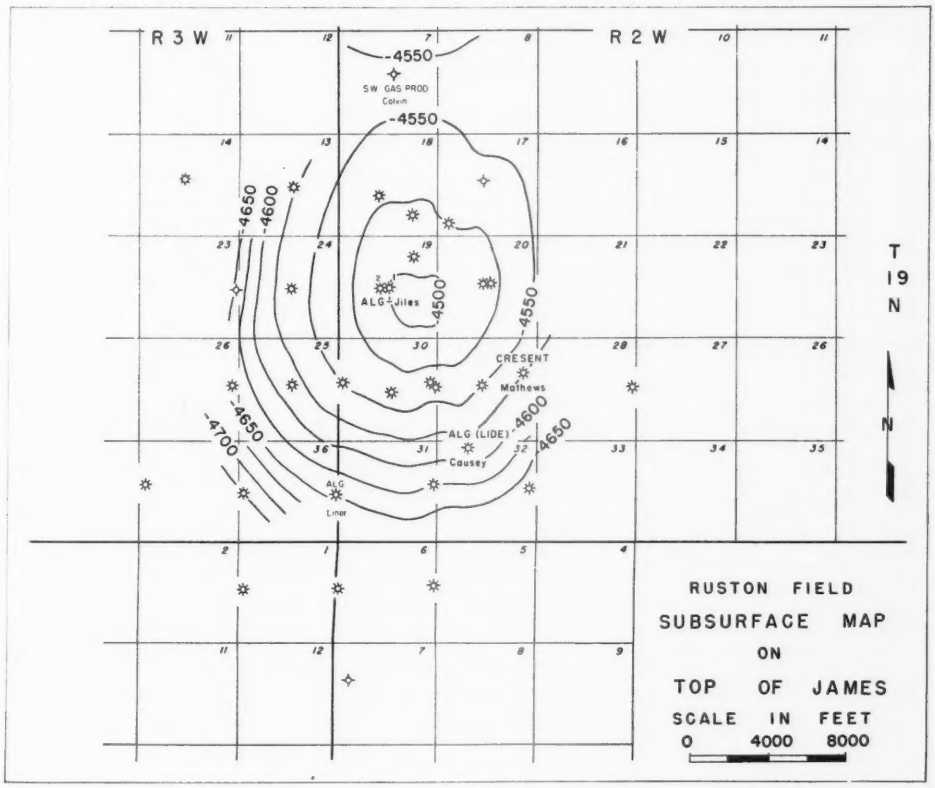


FIG. 7. Subsurface map showing top of James limestone.

10, 1943, through perforations from 5,878 ft–5,896 ft for an open flow of 45,000,000 cubic feet of gas. The producing sand was located approximately 500 feet below the top of the Hosston (Travis Peak) formation. This was the first commercial well in the Ruston field, and it is considered the discovery well.

A considerable amount of drilling activity followed the discovery of gas at Ruston. The five wells drilled during 1944 helped to reveal some of the accuracies and inaccuracies of the surface and seismic surveys. The Arkansas-Louisiana Gas Company No. 1 Liner in section 36, T-19N, R-3W was located largely on the results of the James limestone interpretation from the 1936 survey (Figure 6). This map shows that the No. 1 Liner would have encountered the James limestone only slightly lower structurally than it was in the No. 1 Jiles, the discovery well. The current subsurface studies on the James limestone (Figure 7) show this marker to be 145 feet lower at the No. 1 Liner than it is at the No. 1 Jiles. The Southwest Gas Producing Company No. 1 Colvin, located in section 7, T-19N, R-2W was the first well to confirm the north dip on the structure indicated by the seismic surveys. Additional confirmation of these surveys was made from the 1944 development, which indicated that the apex of the structure was considerably to the north of where it was mapped in the surface survey.

SEISMOGRAPH SURVEY—1944

By 1944, many changes had been made in seismic instruments over the ones used ten years earlier. The use of such devices as automatic gain control, mixing or compositing, magnetically damped geophones, and multiple geophone circuits had become common practice. Generally speaking, these developments in instrumentation and techniques enabled exploration seismologists to map deeper horizons than had been possible during the mid-thirties.

During the summer of 1944, the Arkansas-Louisiana Gas Company made another seismograph survey of the Ruston field area. Most of the instrument developments just mentioned were available, and at least some of them were used.

The objective of this survey was to map the Cotton Valley formation to determine if there was a shift in structural position from that of the lower Glen Rose. A shift was indicated between the surface and the lower Glen Rose and it was only logical to consider the possibility of continued shifting between the lower Glen Rose and the Cotton Valley.

A moderately detailed coverage was made of the area by the use of correlation spreads recorded in a "leap-frog" manner. Most of the area was covered by using 10 geophones on 900 ft spreads with the shot points spaced at $\frac{3}{4}$ mile intervals. An average of two to three shots per hole were taken at an average charge depth of 48 feet. The average charge was $7\frac{1}{2}$ pounds of dynamite, making approximately 20 pounds per shot point. It might be pointed out that this is nearly 19 times as much dynamite as was used in the 1934 survey. However, energy was obtained from an estimated 12,000 ft to 13,000 ft as compared to slightly over 5,000 ft on the 1934 records.

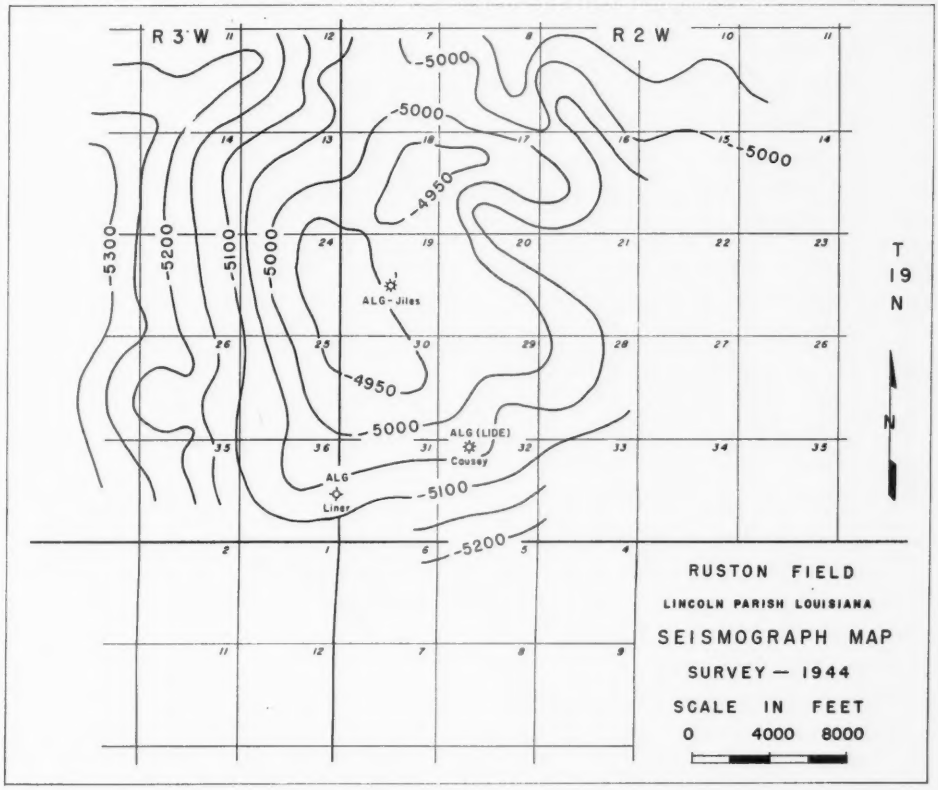


FIG. 8. Reflection seismograph map showing contours near top of Sligo formation.

The only well velocity control available for the area at that time was from the Lide and Greer No. 1 Gardner and the Triangle Drilling Company No. 1 Colvin. These wells were located approximately 8 and 14 miles to the northwest and the southeast of the center of the area respectively. Both wells were much shallower than the depth necessary for Cotton Valley penetration. A composite curve was plotted from velocity data from the two wells, and an equation was derived that would satisfy the curve. From this equation velocities were determined analytically down to the Cotton Valley formation.

Although the primary purpose of the survey was to map the Cotton Valley, an interpretation was made on the Sligo formation (Figure 8). A generalized view of this map would put it in only fair agreement with the present subsurface control. The localized inaccuracies in the mapping of this horizon are probably due to the phasing characteristics of rather poor quality reflections.

The reflections from the Bodcau member of the upper Cotton Valley sand series were generally fair. Quite a number of poor character reflections were obtained from this horizon in the northeastern and extreme southern parts of the

area. A seismic map of the Bodcau sand may be seen in Figure 9. Although this map represented a structural configuration several thousands of feet deeper, it is probably the most accurate delineation of any of the horizons mapped from the three seismic surveys.

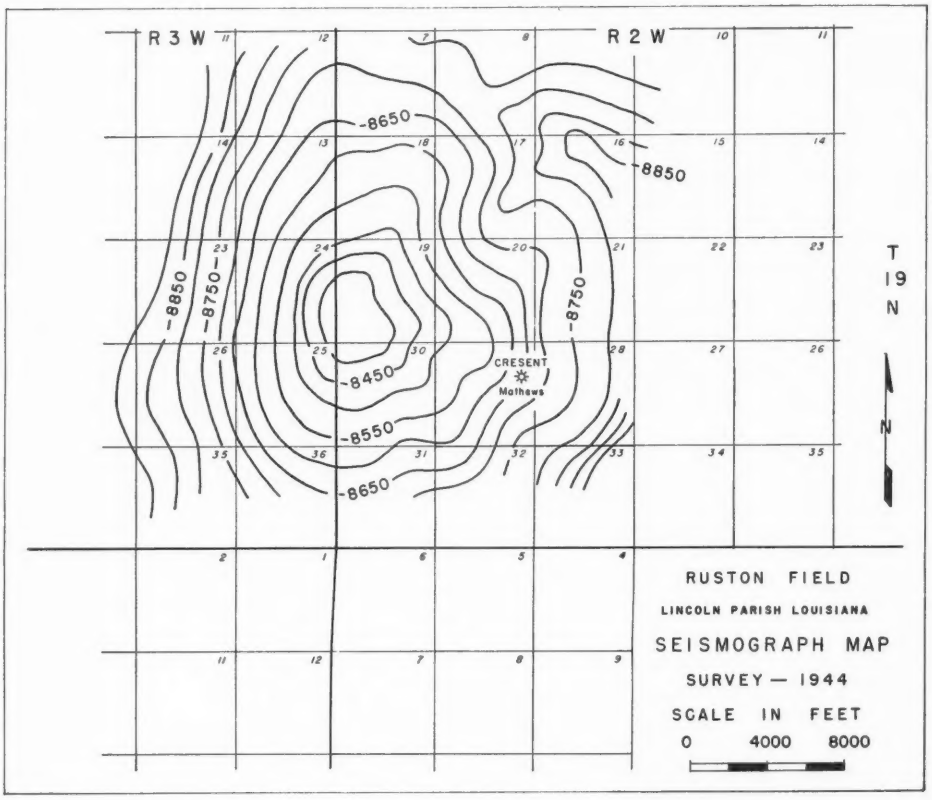


FIG. 9. Reflection seismograph map showing contours on Bodcau sand in the Cotton Valley formation

GRAVITY METER SURVEY

A gravity meter survey was made of the Ruston area by the Arkansas-Louisiana Gas Company as a part of an extended survey in North Louisiana for the purpose of obtaining regional gravity control. This survey, which was completed in 1947, played no part in the discovery or development of the Ruston Field. A gravity map with relative observed values, contoured with 0.2 milligal intervals, may be seen in Figure 10. It shows a rather prominent gravity minimum which is in excellent agreement with the location of the structure. It was included in this paper for the purpose of showing its relationship to the surface and seismic interpretations, as well as to the subsurface control.

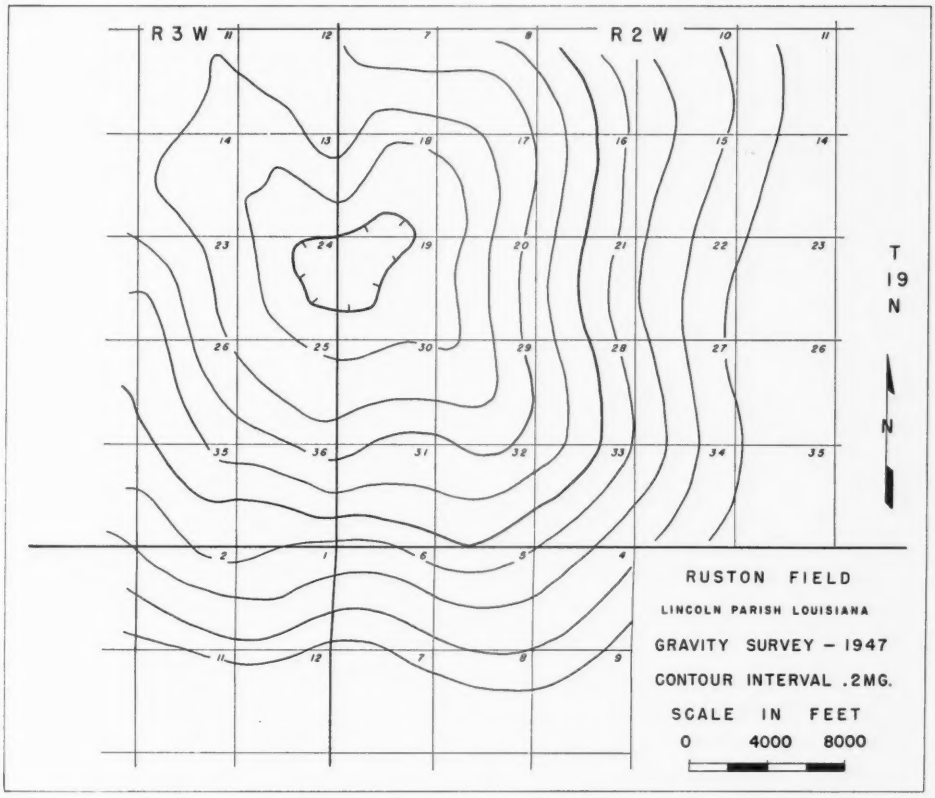


FIG. 10. Observed gravity map. Contour interval is 0.2 mg.

COTTON VALLEY DISCOVERY

It was almost five years after the discovery well was drilled before production was found in the Cotton Valley formation at Ruston. The Crescent Drilling Company No. 1 C. M. Matthews in the NE$\frac{1}{4}$ of section 29, T-19N, R-2W was apparently located by information from subsurface control in the Lower Glen Rose and Hosston wells. It was drilled to a depth of 9,390 feet and was completed on May 5, 1948 in the "D" member of the Cotton Valley sand series through perforations from 8,796 ft–8,806 ft. It tested an open flow of 6,700,000 cubic feet of gas with some condensate. This was the Cotton Valley discovery well of the Ruston field.

A structural map of the Bodcau sand from subsurface control may be seen in Figure 11. Some of the producing wells shown on this map were originally dry holes in formations of the Lower Cretaceous system. They were later deepened and completed in Cotton Valley sands.

A spacing pattern of 640 acres per well has been employed for Cotton Valley

production. Wells producing from the Bodcau and Vaughn sands are located at the centers of the sections, and those producing from the "D" sand are located at the centers of the section lines east or west of the Bodcau and Vaughn wells. This pattern was established by approval of the Conservation Commission of the state of Louisiana.

Referring to the structural map of the Bodcau sand (Figure 11), the wells in

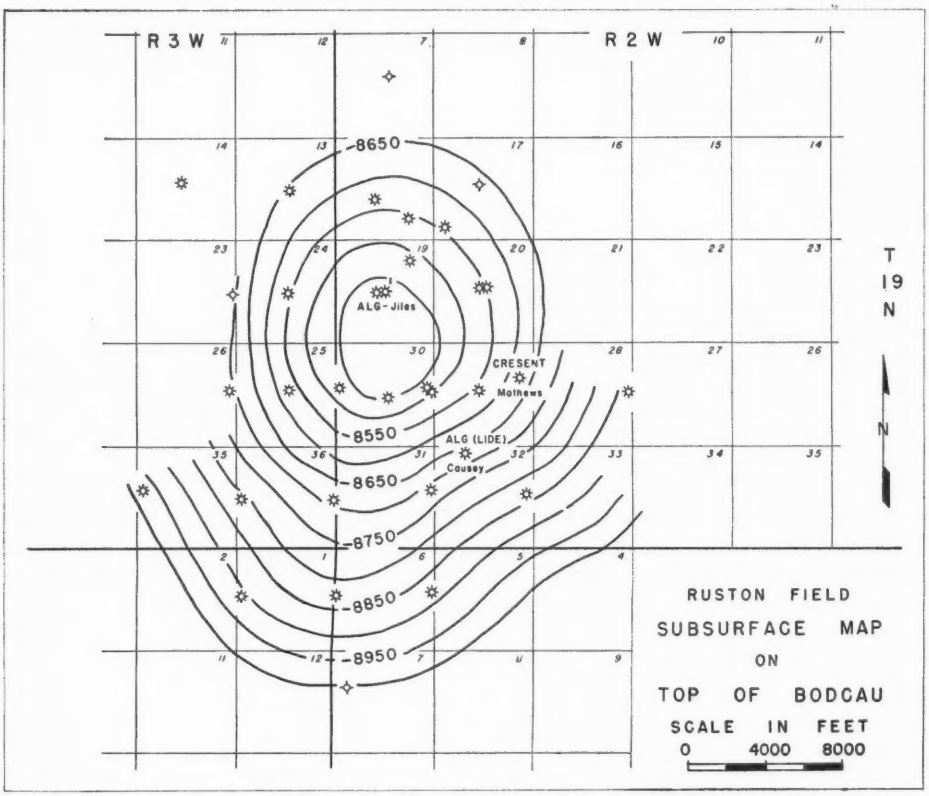


FIG. 11. Subsurface map showing structure on Bodcau member of Cotton Valley sand series.

the southern part of the field are seen to produce farther down dip than those in the northern part of the field. This is because the "D" sand occurring in the southern portion of the field is in part stratigraphic. It pinches out along an east-west strand line near the apex of the structure.

The relationship of the seismic interpretation of the Bodcau sand from the 1944 survey to the present subsurface control on that horizon may be seen in Figure 12. With the exception of the northeastern part of the area, where rather poor records were obtained, this seismic picture is in remarkable agreement with the present structural map.

DEVELOPMENT AND CUMULATIVE PRODUCTION

As of September 1, 1953, a total of forty wells had been drilled in the field. Eleven of these wells were drilled in the lower Glen Rose and Hosston sections; three of them were dry holes, and two had been depleted. Twenty-nine wells, three of which were dry holes, had been drilled in the Cotton Valley formation.

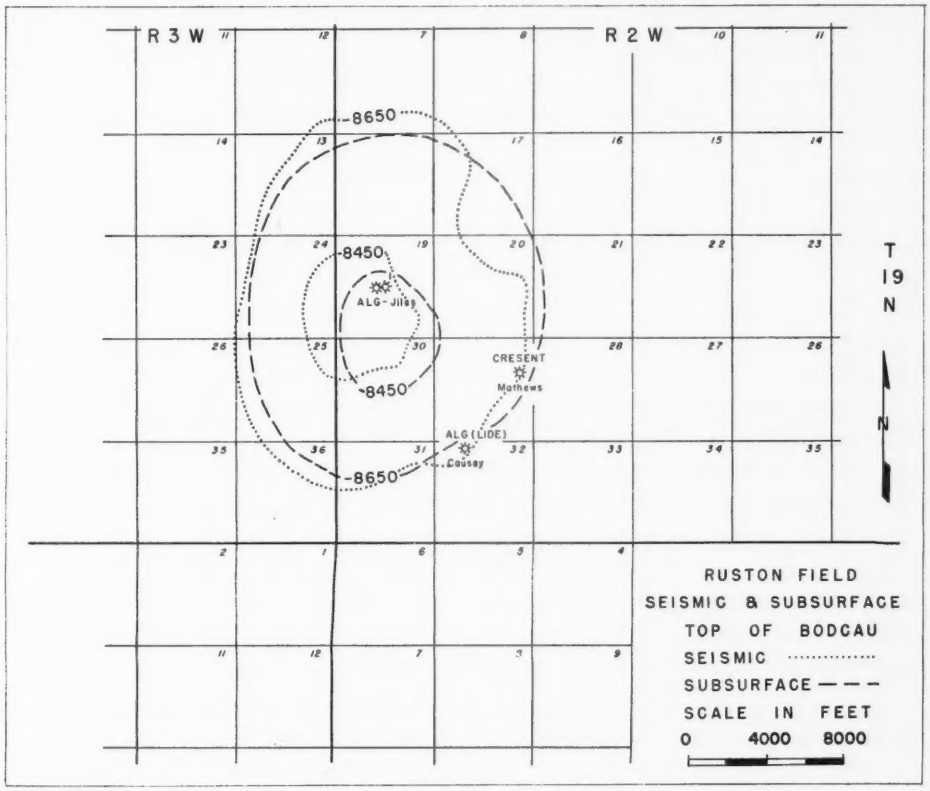


FIG. 12. Comparison of subsurface control on top of Bodcau sand in Cotton Valley formation with seismic picture. Seismic interpretation made four years prior to discovery of gas in Cotton Valley formation.

Of the twenty-six producing wells in this formation, nine were dually completed in the Bodcau and Vaughn sands. One well was completed in the Vaughn sand, and sixteen were completed in the "D" sand.

To January 1, 1953, the field had produced 80,845,221 MCF of gas and 1,432,000 barrels of condensate.

CONCLUSIONS

It would appear that the investigation, the discoveries, and the subsequent development since the surface work first indicated the presence of structure at

Ruston have taken an exceptionally long time. Undoubtedly, there were many factors which prolonged the exploration process. To classify or specify even a few of the factors might seem to be pure speculation. However, one item which seems definitely relevant was the lack of consumer demand to take care of the volume of natural gas available in this section of the country.

It is logical to assume that, if the surface anomaly had coincided with the one indicated by the first seismograph survey, the cost of the initial test and the cost of the last two seismograph surveys might have been saved. It is also logical to reason that, if the decision as to where to locate the initial test could have been postponed until the objective of the 1936 seismograph survey had been fulfilled, the discovery well might have been drilled some seven years sooner. This postponement would have allowed the results of the 1936 survey, which basically confirmed the 1934 survey, to become a factor in that decision.

On the positive side of the picture, it can be definitely stated that the surface survey, made in 1931, by Mr. Oldham of the Arkansas-Louisiana Gas Company, led to the discovery of the Ruston Field. The discovery well, the Arkansas-Louisiana Gas Company No. 1 Jiles, was definitely located by the early seismic interpretations. As regards the high part of the structure, most of the seismic interpretations, as well as the gravity interpretation, are in excellent agreement with subsurface control. From the history presented here, it can be seen that many men in various phases of exploration, including geological, geophysical, land, and scouting, had no small part in the discovery of the Ruston Field.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to the Arkansas-Louisiana Gas Company for permission to publish this paper, and to many employees of the Arkansas Natural Gas Corporation[1] for their assistance in its preparation.

[1] Arkansas-Louisiana Gas Company and Arkansas Fuel Oil Corporation since separation and reorganization of Arkansas Natural Companies, April, 1953.

A MESSAGE FROM THE PRESIDENT

The Executive Committee of SEG has been considering for some time a matter of vital interest to our members; this is the problem of future annual meetings which are scheduled for cities remote from the residences of most of our members.

SEG has been growing very rapidly and at the present time has 4,000 members. The membership of AAPG is approximately 10,000. The increase in size of AAPG and SEG prevents the holding of joint meetings in all but a very few large cities, whereas a separate SEG meeting can be accommodated in a much greater number of cities.

This problem was discussed again during the Executive Committee meeting in Dallas, November 11 to 13, 1953. The Executive Committee of SEG is of the opinion that the interest of our Society can best be served by holding meetings in cities which are in closer proximity to the geographical center of our membership. The committee met informally with the nominees for SEG office for the 1954–55 term, who were entirely in accord with this opinion. Inasmuch as SEG is already committed to joint participation in the St. Louis and New York meetings in 1954 and 1955, it was suggested that the first separate annual meeting of the SEG be held in the fall of 1955, following the joint meeting in New York in the spring of 1955. The desirability of holding the SEG annual meeting in the fall was then discussed informally with the presidents and vice-presidents of the local sections of SEG which presently sponsor the Midwestern Regional fall meeting to make certain that those groups would not feel that the national organization was encroaching upon their prerogatives. The officers of those sections were unanimous in their opinion that there would be no objection to holding future annual meetings of the Society in the fall and that some other time could be selected for their regional meetings.

Following the above informal meetings, the Executive Committee again met in official session and approved the following resolution:

> Whereas, the membership of SEG has now grown to 4,000 and it is in the interests of the members of the Society that annual meetings be held closer to the residences of the majority of the members, and
>
> In order to alleviate the present difficulty of obtaining suitable accommodations in nearby cities in which to hold joint annual meetings with other societies, and
>
> Whereas, it is in the interests of all members of the participating societies to eliminate the present interference in technical paper sessions, and
>
> In order to enable members to attend each other's technical sessions, and
>
> Whereas, during the next few years the AAPG has planned annual meet-

ings in cities remote from our membership, such as Chicago, 1956, and possibly St. Louis again in 1957:

Therefore, be it resolved that after the 1955 joint annual meeting with the AAPG and SEPM, the SEG will henceforth hold separate annual meetings during the fall season.

The above resolution was unanimously adopted by the Executive Committee.

Mr. John Emery Adams, President of AAPG, was notified on November 13, 1953 of that decision with the assurance that SEG desires to continue to cooperate with AAPG in all other matters of vital interest to our respective societies, including an interchange of speakers for annual, regional and local meetings, and reciprocal invitations to the members of each society to attend the other's meetings. We further stated we will continue to encourage SEG local sections to meet with local geological societies so that our respective members can continue to enjoy the benefits of the close association existing during these many years.

ROY L. LAY, *President*
Society of Exploration Geophysicists

November 30, 1953

STYLE GUIDE FOR *GEOPHYSICS*

MILTON B. DOBRIN*

ABSTRACT

The purpose of this paper is to revise Nettleton's instructions on the preparation of manuscripts for GEOPHYSICS and to bring them up to date. New material is included on various points of style such as headings, footnotes, figure captions, capitalization, abbreviations, etc. Authors of papers for GEOPHYSICS are urged to make use of the suggestions presented here when preparing their manuscripts. Their cooperation in this respect should ease the work load of the present Editor as well as of future editors. More important, it should help to achieve a greater uniformity of style throughout the journal.

INTRODUCTION

For more than eight years, prospective authors of papers for GEOPHYSICS have been referred to an article by Nettleton (1945) for instructions on how their manuscripts should be prepared. The information in this article has proved so valuable to authors and subsequent editors alike that the present Editor has been encouraged to enlarge its scope and to bring it up to date. He hopes that the set of instructions that follows will serve as a usable guide to authors on many questions of style and form that may arise in preparing a manuscript.

In 1947, *A Manual of Style* of the University of Chicago Press was adopted as the standard rule book for GEOPHYSICS. This remains our basic guide, but certain departures have come to be accepted. In matters of geologic terminology, for example, the standards of the United States Geological Survey take precedence. Moreover, the University of Chicago manual is so long (almost 500 pages), involved, and hard to obtain that we do not ask our authors to follow it in preparing their manuscripts. A short manual summarizing our present practice regarding such frequently encountered points of style as reference citations, footnotes, abbreviations, figure captions, etc. should be of more practical aid to the author. The Editor requests that authors cooperate as much as possible in observing these instructions in order to lighten his work load in maintaining uniformity throughout the journal. Such uniformity is essential in any high-calibre publication.

The specifications that follow should be looked upon as suggestions for helping the editors and printer rather than as requirements that must be observed before contributions will be accepted.

TYPES OF MATERIAL ACCEPTED

In addition to technical papers, we welcome letters to the Editor, discussions, and reviews of the geophysical literature. All contributions should be in English, and the technical papers must not have been published previously. Moreover, they should not be under consideration for publication elsewhere. Translations of

* Magnolia Petroleum Company, Dallas, Texas. Editor of GEOPHYSICS for 1953–55 term.

papers published or under consideration for publication in any foreign language are not normally accepted, although in certain instances such material may be solicited.

In general, contributed papers should relate to petroleum, mining, or engineering geophysics. The relation need not be direct. For example, any manuscript on fundamental scientific principles that are basic to geophysical exploration methods would be welcome.

No paper submitted as Part I, II, etc. of several installments can be accepted with such a designation in the title unless all installments are submitted at the same time, so that the entire set can be judged as a unit.

HANDLING OF MANUSCRIPTS

All manuscripts, except for reviews, should be submitted in duplicate to the Editor. The reviews should go to the Chairman of the Reviews Committee. The Editor will ordinarily forward a copy of each manuscript to one of the Associate Editors, who will examine the paper himself and who may then send it to one or more referees who are well informed in the field covered by the paper. The Associate Editor will return the manuscript, accompanied by any comments and recommendations he might have as well as those of the referees, to the Editor. The Editor at this stage decides on final action and advises the author of his decision. He will either accept the paper, reject it, or return it to the author for revision. Accepted manuscripts are "styled" for the printer, either by the Editor or an Associate Editor. The printer mails galley proofs and one copy of the original manuscript to the author for checking, and the author returns them, with his corrections, to the Editor. Page proofs are not sent to the author.

The procedures outlined in this section are subject to change from time to time.

GENERAL FORM FOR MANUSCRIPT MATERIAL

Two copies of each manuscript should be submitted if possible. All manuscripts should be typed double-spaced on $8\frac{1}{2}'' \times 11''$ (or $8'' \times 10\frac{1}{2}''$) paper. Only one side of a sheet should be used. All equations except simple ones that a typewriter can handle should be neatly inserted in ink. Special pains should be taken to make all the mathematical material clearly legible to the typesetter.

Along with the original illustrations (or good-quality glossy photographic prints), the author should send an extra set of prints which will accompany the second copy of his text. This extra set may be reproduced from the originals by any convenient process such as photostat, ozalid, or offset. If the prints can be reduced to $8\frac{1}{2}'' \times 11''$ in size, handling of the manuscript material will be simplified for the author, editors, and referees alike.

When drawings larger than $8\frac{1}{2}'' \times 11''$ are on tracing paper or tracing cloth, it is generally possible to fold them to letter size without injury. If this is done, the drawings can be included in the same envelope as the manuscript and the

author can avoid the inconvenience and expense of wrapping and mailing bulky and often unwieldy packages.

Our printer suggests that authors bear in mind the following rules on preparation of manuscript material in order to facilitate typesetting and thus keep printing costs down:

1. Use standard typewriter paper—8½×11 inch sheets. Avoid colored paper and lightweight stock.
2. The typewritten lines should not exceed 5½ or 6 inches in length.
3. All typed material should be double spaced. Please do not use single spacing for footnotes, quoted matter, bibliographies, and so on. These materials are almost always more difficult to set and to proofread than straight text and there is no point in making them more difficult by single spacing.
4. If a correction is to be made in the typed copy, write it in at the same level as the line in which it is to appear.
5. When an addition is to be made the sheet should be cut and the insert pasted in its proper place. Only brief inserts of a word or two should be attempted in the margin.
6. Footnotes should be typed on separate sheets or at the bottom of the page. They should never be run into the text.

PREPARATION OF ILLUSTRATIONS

All line drawings should be made with black drawing ink on white paper (preferably tracing paper) or tracing cloth. Figure numbers and captions or titles should not be lettered on the figure itself, since it is our policy to have the figure number and each caption set up in type below the figure. The figure numbers and author's last name should, however, be written in pencil on the margins for identification by the printer. Drawings made originally for lantern slides often have captions, and in some cases figure numbers, lettered in. It is best to blank these notations out by covering them with strips of white paper that can be pasted into place.

In general, the linear dimensions of a line drawing should not be greater than twice the dimensions of the printed figure. If a greater reduction is necessary, the lines in the printed figure tend to be too thin. Also the larger the original drawing the greater the temptation to crowd too much material into the space that becomes available.

The author should make sure that all lettering on his illustrations will be legible after reduction. Nettleton's 1945 article contains three charts by which the author can gauge the legibility of his lettering after reproduction. These charts need revision because the margins of the pages in GEOPHYSICS were narrowed in 1947 and the "type page" size correspondingly increased. The corrected diagrams are presented here.

Figure 1 (originally modeled after Moore, 1942) enables the author to tell whether the copy in an original drawing will be legible when the drawing is reduced either to full-page width or full-page length. The illustration should be held up or tacked on a wall and the maximum distance at which it is legible should be determined. If this distance is plotted against the length of the original,

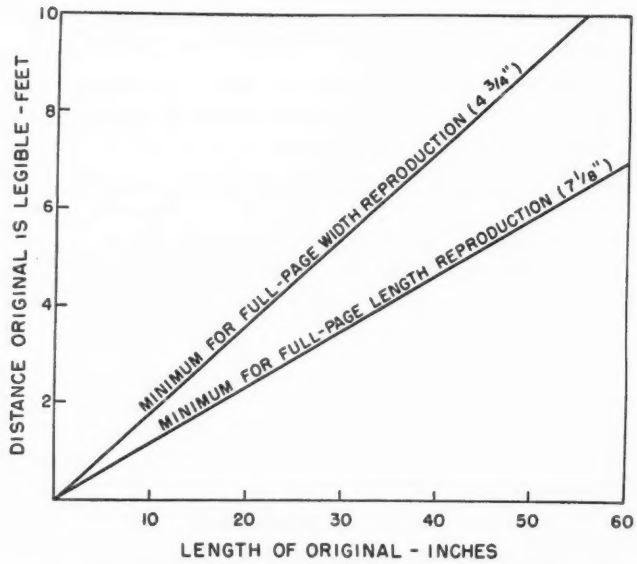


FIG. 1. Relation between the size of a drawing and its legibility after reduction either to full-page width or full-page height in GEOPHYSICS. If the point falls above a line the drawing should be legible at the indicated reduction. If it falls below, it would be illegible (after Moore and Nettleton).

the position where the point falls with respect to the lines tells whether it will still be legible when reduced to full-page length or full-page width, or whether it would have to appear as an expensive (and hence, to the Editor, abhorrent) folded insert.

Another way to test legibility of a figure after reduction has been suggested by Dr. Nettleton. Put the original drawing on a wall. Mark, on a piece of paper, the maximum dimension the figure will have when it is printed. Hold the paper at normal reading distance (10–14 inches) from the eyes and sight across the marks toward the drawing. Back away until the marks appear to coincide with the maximum dimension of the drawing. If the original can be read clearly from this distance, the reproduction should be satisfactory. If not, the letters are too small for the final dimensions proposed.

The charts shown in Figures 2 and 3 should be particularly valuable because the author can use them to determine the proper sizes for his letters before they are drafted on the original. Nettleton recommends a minimum letter height of 0.03 inch on the printed page. For a drawing to run the full width of a page in GEOPHYSICS ($4\frac{3}{4}$ inches), Figure 2 gives the minimum height of lettering as drafted in terms of the width of the origin. Figure 3 gives the corresponding information for an illustration that is to extend the full height of a page ($7\frac{1}{8}$ inches). Where the reduction will be substantial, the spacing between letters and words should also be increased.

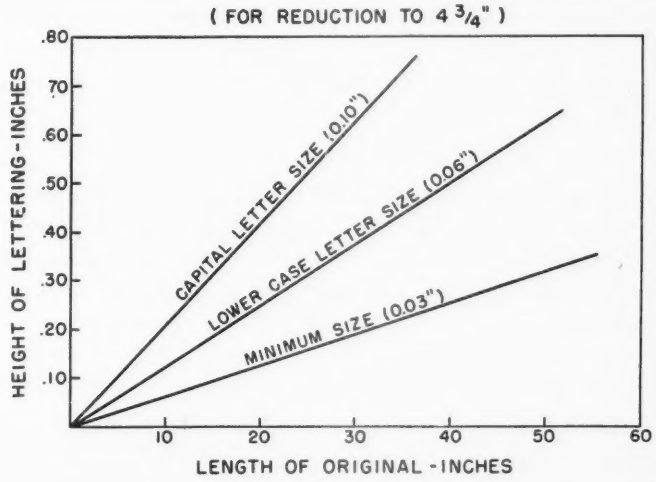


FIG. 2. Relation between size of lettering on original drawing, length of drawing, and size of lettering after reduction to full-page width in GEOPHYSICS. The upper two slanting lines refer to sizes of letters in the text of this paper. The lower slanting line shows the minimum letter size that will be legible after reduction. This chart can be used to choose lettering-guide sizes since the number of the guide gives the height of the letter in thousandths of an inch (after Nettleton).

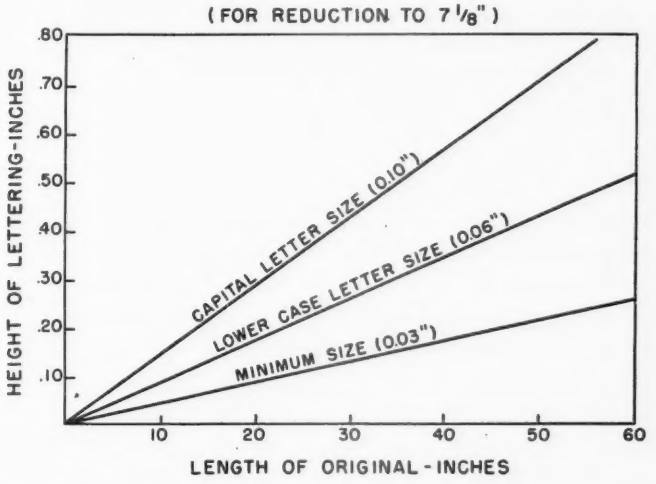


FIG. 3. Same as Figure 2 but for reproduction as full-page illustration (after Nettleton).

TITLE

The title of a paper should be as brief as possible. Whenever it requires more than one line of type, a shortened version must be prepared by the Editor or printer for the running heads used after the first page. The first word of the title

should, if possible, be a significant one that will be suitable both for classifying and indexing the paper. If the paper has been given orally at a meeting, a footnote should specify the organization holding the meeting and the date of the presentation.

ABSTRACT

Every paper must be accompanied by an abstract. Its length should normally be limited to 200 words. A good abstract should emphasize the conclusions reached in the paper and should not be simply a list, in sentence form, of the topics the paper covers. All authors are urged to read the brief but excellent essay by Landes (1952) entitled "A Scrutiny of the Abstract."

FIGURE CAPTIONS AND TEXT REFERENCES

Each illustration should be given a figure number (not plate number) and should be referred to by that number in the text. Numerals for this should be Arabic.

Each figure should have a caption or title. All of the captions should be listed together on one or more separate sheets of paper. Each caption should be explicit enough that the significance of the illustration can be understood by the reader without reference to the text. The caption for each figure should be preceded by the figure number (in the form FIG. 3) and it should end with a period. In text references, "Figure" should be spelled out and capitalized.

HEADINGS

Two types of headings are customarily used in GEOPHYSICS. Principal headings are capital-letter center headings, such as the one used just above this paragraph. Sub-divisions of items covered by the center headings are accomplished by using side-headings in italic type. Main headings should be typed at the center of the page in capital letters. Headings of next lower rank should be typed from the left side, without indentation. Only important words should be capitalized, and the entire heading should be underlined, to signify italic type. The text following the heading should start on the next line. If headings of lower rank than these are desired, they too should be typed lower case (except beginning letters of key words) and underlined: they should be indented and the text should start immediately after the heading on the same line. A period and dash should separate heading and text. Still lower rank headings are similar to this one but are introduced by lower case letters as shown below.

The various headings will appear in type as follows:

MAIN HEADING

First Subsidiary Heading (italic type on line by itself: no punctuation)

Second Subsidiary Heading.—Text follows on same line.

a) Third Subsidiary Heading.—Text follows on same line.

b) " " " " " "

BIBLIOGRAPHIC REFERENCES

In the 1945 instructions to authors, footnote references were specified for GEOPHYSICS. Recently a group of editors of geological publications has recommended the adoption of uniform styles for literature citations and bibliographic references. Specifically, they have proposed that all journals in the earth sciences use the form that is standard in U. S. Geological Survey publications. Most of the leading geological journals have been using a style that is quite similar except for details of punctuation. At least three of them have already made changes in their own systems to bring them into complete conformity with the usage of the U. S. Geological Survey.

Because uniformity in reference citation among related journals has obvious advantages to authors and readers alike, the present Editor, with the concurrence of the Publications Committee, is adopting the U. S. Geological Survey's system for GEOPHYSICS. A description of this system follows.

All references should be grouped alphabetically by author at the end of the paper. The list should be headed REFERENCES.

In the text, literature citations should be referred to with the year of publication in parentheses after the author's name. If the author is not referred to by name in the text itself, his name and the year should be inserted in parentheses at the point where the reference applies. If there are several references by the same author they should be listed at the end in chronological order. If an author has more than one reference for the same year, letters *a*, *b*, etc. should be put after the year for the respective references. Any citation of specific pages in the reference should be with the parenthetical text insertion as shown in the example below.

For references to *papers in journals* the following order and punctuation should be observed:

Author(s) —Last name(s) first, then initials or first name(s).
Comma
Year of publication
Comma
Title —Capitalize only first word of title and proper nouns (except in German where all nouns are capitalized). No quotation marks unless they are actually a part of the title.
Colon
Journal name —Conventional abbreviation preferred.
Comma
Volume number —Arabic numerals; use abbreviation: v.
Comma
Page number —p. Where possible use beginning and ending pages, giving all numerals in both.
Period

For references to *books:*

Author(s) —As above.
Comma
Year of publication
Comma
Title —Capitalize as above.
Colon
Place of Publication—City only, not state or country.
Comma
Publisher —Firm name.
Period

It is hoped that the following example will clarify these instructions.

Sample

The fact that the interpretation of anomalies in any of the potential fields is fundamentally incapable of a unique solution has also been emphasized (Nettleton, 1940, p. 101–102; Skeels, 1947). . . . It is interesting to calculate the ratio for some of the values given by Nettleton and Elkins (1944) as a result of their theoretical calculations. . . . One example of such an application is the careful study by Haalck (1929) of the Kursk anomaly in Russia.

References

Haalck, H., 1929, Zur Frage der Erklärung der Kursker magnetischen und gravimetrischen Anomalie: Gerlands Beitr. Geophysik, v. 22, p. 241–255.

Nettleton, L. L., 1940, Geophysical prospecting for oil: New York, McGraw-Hill Book Co., Inc.

——— and Elkins, T. A., Association of magnetic and density contrasts with igneous rock classifications: Geophysics, v. 9, p. 60–78.

Skeels, D. C., 1947, Ambiguity in gravity interpretation: Geophysics, v. 12, p. 43–56.

FOOTNOTES

All footnotes introduced in the text of a paper should be numbered consecutively from the beginning to the end of the manuscript. The footnotes referring to the title and the name of the author should not be numbered, since they are indicated by asterisks and daggers, respectively. In the typescript, footnotes may be inserted at the bottom of the page to which they refer or they may be typed on separate sheets. Bibliographic references should not be given in footnotes but in a list at the end of the paper, as designated in the preceding section.

MATHEMATICAL MATERIAL

One of the most expensive operations in publishing a technical journal such as GEOPHYSICS is setting mathematical formulas into type. The author can help in reducing these costs by putting his equations into a form that will simplify the typography. Often a complicated expression can be simplified if the various terms making up the expression are assigned symbols which are defined individually. The paper by Tolstoy and Usdin (1953) in the October, 1953 issue of GEOPHYSICS furnishes some good examples.

Where convenient, the shilling fraction using the solidus (/) should be used

rather than the built-up fraction (two decks). For very long and complicated fractions, however, the solidus is not always suitable.

Fractional exponents should be used instead of radicals wherever feasible. Radicals are preferred, however, for simple square roots; e.g. $\sqrt{2}$ rather than $2^{1/2}$.

Subscripts and superscripts, where there is any doubt as to whether they will be clear to the typesetter, should be indicated by carets and inverted carets: for example

It will be helpful to the printer if Greek letters and other unusual symbols are labeled where they are introduced for the first time. A "kappa" will not be set up as a "*K*" or an "epsilon" as an "*e*," if there is a marginal notation of "capital kappa" or "lower case epsilon," connected with the character in question by a pencilled line. A list of all symbols used in a manuscript, on a separate sheet of paper, would be much appreciated by the typesetter if many of them are at all unusual.

All equations should be punctuated where their position in the sentence calls for punctuation. An equation ending a sentence should be followed by a period. An equation should be followed by a comma where good English usage requires a comma at that position in the sentence.

The printer is instructed to set all mathematical symbols and all isolated letters in the text in italic type if there are no markings to the contrary. Italics are proper in the case of all symbols for scalar quantities. Symbols signifying vector quantities, on the other hand, should be set in roman, boldface. A *wavy line* should be drawn under such symbols and "roman boldface" written in the margin at the point where the vectors are first introduced.

With the object of standardizing space and time coordinates, we suggest the following: Lower case letters x, y, and z should be used for cartesian space coordinates. Corresponding axes are designated by x-axis, y-axis, and z-axis. The time coordinate is designated by t. For representing travel time and step-out time of seismic waves, t and Δt should be used in preference to T and ΔT. Figures should be lettered consistently with these conventions.

When referring to equations by number in the text, put the numbers in parentheses: e.g. "As shown in equation (10), ..."

CAPITALIZATION, ABBREVIATIONS, PUNCTUATION, ETC.

The following instructions are taken from *A Manual of Style* published by the University of Chicago Press (1949). The selections listed below have been chosen because they appear to be especially pertinent to manuscripts for GEOPHYSICS.

Capitalization

The following rules may be especially useful to writers on geophysical topics.

1. Capitalize accepted geographical names. Examples: Mississippi River, Gulf Stream, Rocky Mountains.

2. Capitalize physiographic and geological terms only when they are part of a name: Delaware Basin, Edwards Plateau, Hockley Dome, Mesa Verde, Hudson Valley.

3. Capitalize trade names. Examples: Hydrofrac, MicroLog, Aquagel.

4. Capitalize words designating points of the compass when they indicate geographical parts of the country or of the world. Examples: the Middle West, the South, the Equator, East Texas, West Texas. But do not capitalize nouns or adjectives derived from such names. Examples: middle western states, the south of Florida.

5. Capitalize tems for political divisions when they are used as proper names, but not such words as "city" or "state" when standing alone. Examples: Mexico City, the state of Texas.

6. Capitalize official titles of organizations and institutions. Examples: Society of Exploration Geophysicists, The Texas Company. (If one of the words in a title stands alone, as "our company policy" it should not be capitalized.)

7. Capitalize geologic names as specified by the rules of the U. S. Geological Survey (Wood, 1935, p. 6–8). All eras, periods, and systems are capitalized, except for pre-Cambrian. The adjectives "upper," "middle," and "lower," when used with "Carboniferous," "Tertiary," or "Quaternary" should not be capitalized unless the term is quoted. When used with the names of other systems they may be capitalized if the term is definite. When applied to sub-divisions of series or to indefinite or local sub-divisions of stratigraphic units they should not be capitalized.

Lithologic terms should generally not be capitalized. Examples: Austin chalk, Potsdam sandstone. Designate oil and gas fields as in the following examples: Cushing oil field, Hugoton gas field.

8. Capitalize the first word after a colon only when introducing a complete passage or sentence having independent meaning. For example, "The third law of motion is: Action is equal and opposite to reaction."

9. The word "Figure" when followed by a number should be capitalized in the text. Do not capitalize the word "equation" when it precedes a number.

Abbreviations and Spelling

In general, all words should be spelled out except those which it is common usage to abbreviate. The following rules cover many of the abbreviations encountered in papers on geophysics.

1. Dimensions, degrees, distances, weights, measures, etc. should be expressed by numerals. Examples: 15 ohms, 240 volts. Exception: spell out small numbers up to three, as one ohm, two volts, etc.

2. Regardless of rule 1, spell out all numbers that begin a sentence except for

dates. Examples: "Fifteen miles from Tulsa, . . . ," "1932 was a depression year."

3. For cases not covered by rules 1 and 2, spell out all numbers smaller than eleven.

4. Spell out round numbers (units of 100 up to 1,000 and 1,000 in larger numbers). Example: "The attendance was estimated at five hundred" (but "at 550").

5. Use commas in numbers of more than three digits (except dates). Example: 1,714.

6. A decimal less than unity should be preceded by a zero. Example: 0.07. Exception: Arrival times of seismic events when less than one second, as .723 seconds.

7. Spell out names of months, except in tables.

8. Do not abbreviate parts of geographic names. Examples: Mount Wilson, North Dakota. Exceptions: St. Louis, Ste Genevieve.

9. Units of measurement such as km, ft, ft/sec, kc etc. should be abbreviated as shown when preceded by a number. The period should not follow such abbreviations except in the case of those which otherwise might be confused with other words. Thus "no." is the abbreviation for "number." The omission of the period is a departure from the University of Chicago Press style manual rules, but it is in agreement with current practice in most technical journals and is recommended by the American Standards Association.

10. The following abbreviations, standing for both singular and plural, are acceptable:

A	angstrom unit	inch	inch (do not abbreviate except in form lbs/in^2; do not use ″)
AM	amplitude modulation		
ac	alternating current		
amp	ampere	kc	kilocycle
atm	atmospheres	km	kilometer
bbl	barrel	km/sec	kilometer/second
cc	cubic centimeter	kw	kilowatt
cps	cycles per second	lb	pound (do not use #)
db	decibel	mc	megacycle
dc	direct current	mg	milligal
FM	frequency modulation	mgm	milligram
ft	foot (do not use ′)	mm	millimeter
ft-lb	foot-pound	mph	miles per hour
gm	gram	no.	number (do not use #)
hp	horse power	rpm	revolutions per minute
		sec	second
		w	watt

11. Certain organizations, which a large proportion of our membership would refer to by their initials, should be abbreviated without periods or spaces between letters, as follows:

SEG	Society of Exploration Geophysicists
AAPG	American Association of Petroleum Geologists
MIT	Massachusetts Institute of Technology
GSA	Geological Society of America
AGU	American Geophysical Union
SEPM	Society of Economic Paleontologists and Mineralogists
EAEG	European Association of Exploration Geophysicists
AAAS	American Association for the Advancement of Science
AGI	American Geological Institute

These are the only organizations for which this form of abbreviation is recommended in GEOPHYSICS. Other abbreviations of organizations use the periods. In references, use Bull. A.A.P.G., Bull. G.S.A., etc.

Punctuation

Of the many rules of punctuation listed in the University of Chicago Press *Manual of Style*, only a few need be referred to here. The items indicated below are included because authors of manuscripts for GEOPHYSICS have been highly inconsistent in their usage with respect to these particular points.

1. In a series of three or more items, where the last of the series is preceded by the word "and," place a comma before the "and." Example: apples, oranges, and bananas; or apples, oranges, etc.

2. Periods and commas are always placed *inside* quotation marks. Semicolons, however, go outside.

3. A period goes inside the parentheses or brackets when the matter enclosed is an independent sentence, otherwise outside. A comma or semi-colon follows the parenthesis if the context requires it.

4. "As follows" or "the following" requires a colon if followed directly by the terms enumerated. If the statement in which such a phrase appears is complete and followed by other sentences, use a period.

5. Hyphenate two or more terms which together act as an adjective modifying a subsequent term. Examples; "short-circuited transformer." "base-of-weathering reflection."

6. Hyphens should be used when compound words are made with "cross," "self," "half," quarter," "vice." Examples: cross-correlation, cross-section, self-inductance, quarter-wave, vice-president.

Miscellaneous

1. Write "percent," "stepout," "borehole," "shotpoint" as one word.

2. GEOPHYSICS (the name of this journal) should be in capital letters except in references.

3. Quotations from other authors which are a sentence or more in length should be started on a new line, and indented only if the selection quoted begins a paragraph in the original text.

READABILITY

It is seldom that authors of papers for GEOPHYSICS violate the more common rules of grammar as taught in high school and college English courses. A shortcoming much more frequently encountered in technical manuscripts is poor readability. By this is meant an undue complexity of style that is hard for most readers to follow. A reader will plough through unnecessarily complex writing only if he has to; otherwise his interest will fall off rapidly.

Some excellent pointers on improving readability are given in a book by Gunning (1952). To paraphrase a few of them: Keep sentences short. Prefer the simple to the complex. If a short word conveys the same meaning as a word of many syllables, choose the shorter one. Put strength into your verbs rather than relying on your adjectives. Where there is a choice, use concrete rather than abstract terms. Maintain variety in your style. Avoid the passive voice.

Technical writing must by its very nature be more complex than writing for publications on the news stands. Nevertheless, there seems to be much room for improving the readability of technical literature. If technical subject matter is complex to begin with, the author should not complicate it further by using involved sentences and unnecessary words. The most effective way to make a manuscript clear is to revise it over and over, keeping in mind principles such as those quoted above from Gunning's book.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the assistance given by Mr. T. A. Elkins, Dr. M. K. Hubbert, Mr. Paul L. Lyons, Dr. L. L. Nettleton, Dr. Sigmund Hammer, and Dr. J. P. Woods in the preparation of this article. Although all of them have offered valuable suggestions, the Editor must take the responsibility for any inadequacies or iniquities in the final product.

REFERENCES

Gunning, Robert, 1952, The technique of clear writing: New York, McGraw-Hill Book Company, Inc.

Landes, K. K., 1952, A scrutiny of the abstract: Geophysics, v. 17, p. 645.

Moore, Carl A., 1942, Preparation of lantern slide copy: Bull. A.A.P.G., v. 26, p. 1656–1671.

Nettleton, L. L., 1945, Preparation of manuscripts for publication in GEOPHYSICS: Geophysics, v. 10, p. 421–428.

Tolstoy, I. and Usdin, E., 1953, Dispersive properties of stratified elastic and liquid media: a ray theory: Geophysics, v. 18, p. 844–870.

University of Chicago Press, 1949, A manual of style, 1949 revision: Chicago.

Wood, G. M., 1935, Suggestions to authors of papers for publication by the United States Geological Survey, 4th ed.: Washington, U. S. Govt. Printing Office.

INTRODUCING THE ASSOCIATE EDITORS OF GEOPHYSICS

Beginning with the current volume, the Editor of GEOPHYSICS will be assisted in the performance of his duties by a number of Associate Editors who have been appointed by the President of the Society of Exploration Geophysicists. The new associate editorships were created late in 1953 by action of the Society's Executive Committee in order to lighten the Editor's work load, which has increased greatly with the rapid expansion in the volume of technical material published in each issue of GEOPHYSICS over the past few years. This action was the result of several years of study initiated by the Publications Committee of my predecessor, Mr. Paul Lyons, and continued by the present Publications Committee with the aid of a number of former editors.

Five associate editorships have been established, each for a major division of geophysical prospecting. These divisions are: gravity, seismic theory and fundamentals, seismic techniques and operations, magnetics, and electrical prospecting. Each associate editor will handle the technical evaluation of manuscripts falling within the division which he has been assigned. He will normally select and correspond with referees for the various manuscripts and will pass on the referees', and in many cases his own, comments to the Editor, who will still be responsible for final action on each paper.

The Associate Editor for Gravity is *Thomas A. Elkins*, of the Gulf Research and Development Company, Pittsburgh, Pennsylvania. Mr. Elkins joined the Gulf organization in 1930 and has been associated with its gravity interpretation group ever since. He is the author of many papers on gravity interpretation which have appeared in GEOPHYSICS over the past 15 years. He was first chairman (1945–47) of the Society's Reviews Committee.

Dr. Norman Ricker is Associate Editor for Seismic Theory and Fundamentals. He is an early pioneer in geophysics, having been Humble's first Chief Geophysicist. Since 1938, he has been Senior Research Physicist at the Research Laboratories of The Carter Oil Company in Tulsa. He has developed the wavelet theory of seismogram structure and has published numerous papers, mostly in GEOPHYSICS, on this and related fundamental studies in seismic wave propagation. Recently Dr. Ricker has toured the Society's local sections as SEG Distinguished Lecturer for the 1953–54 season.

For Seismic Techniques and Operations, the Associate Editor is *Dr. L. Y. Faust* of Amerada Petroleum Co., Tulsa. Dr. Faust is a geophysical supervisor at Amerada in charge of special problems. He has given particular attention over many years to seismic velocities and was author of a paper in GEOPHYSICS on this subject which received the Society's Best Paper Award for 1951. He has been with Amerada since 1930.

For Magnetic Prospecting, the Associate Editor is *Victor Vacquier*, Professor of Geophysics at the New Mexico Institute of Mining and Technology. Prof. Vacquier entered geophysical work in 1930 for Gulf Research and Development

Co., where he was engaged in magnetic research and instrument development. While at Gulf, he developed an airborne magnetometer for prospecting applications but before it could be adapted for this purpose it was taken over for submarine detection in World War II. Later it formed the basis for the Gulf airborne magnetometer. In 1942, he was transferred to the Airborne Instruments Laboratory of Columbia University and in 1944 joined the staff of Sperry Gyroscope Company as a Marine Instruments Engineer. He accepted his present academic position in 1953.

Dr. Irwin Roman of the U. S. Geological Survey, Washington, D. C., is Associate Editor for Electrical Prospecting. Active in geophysical work since the middle 1920's, Dr. Roman has made contributions to all branches of prospecting. From 1925 to 1930, he was employed by Amerada and the Geophysical Research Corporation. Later he was on the faculty of Michigan College of Mining and Technology. Since 1935 he has been a geophysicist with the U. S. Department of the Interior (Bureau of Mines and later the U.S.G.S.) specializing mainly in mathematical research on electrical prospecting.

The Editor feels most fortunate to have the benefit of consultation with such a distinguished group of geophysicists in the evaluation of manuscript material. He appreciates their willingness to serve and looks forward to a considerable improvement in the quality of the journal as a result of this new association.

PATENTS

O. F. RITZMANN*

ELECTRICAL PROSPECTING

U. S. No. 2,652,530. S. Davidson. Iss. 9/15/53. App. 2/13/48.

Electromagnetic Induction Method and Apparatus for Locating Subterranean Electrically Conductive Bodies. A low frequency electromagnetic prospecting system using a vertical energizing coil and a horizontal pick-up coil whose signal is compared in phase with the energizing current, the pick-up coil being mechanically oscillated about a horizontal axis to insure perpendicularity of the coils at some position in the oscillation.

U. S. No. 2,653,220. C. A. Bays. Iss. 9/22/53.

Electromagnetic Wave Transmission System. A system for transmitting electromagnetic wave energy by locating a transmitter and receiver in a high-resistivity earth stratum which is bounded on either side by strata of lower resistivity so as to form a wave guide.

GRAVIMETRIC PROSPECTING

U. S. No. 2,648,055. N. J. Smith and R. I. Smith. Iss. 8/4/53. App. 7/11/51.

Apparatus for Detecting and Recording Measurements of Seismic, Gravitational, and Other Forces. A seismometer or gravimeter having an inertia element connected to a transducer with the assembly mechanically rotated about an axis inclined to the axis of the transducer and the output recorded or measured.

U. S. No. 2,650,991. R. W. Ketchledge. Iss. 9/1/53. App. 11/14/47. Assign. Bell Telephone Laboratories, Inc.

Accelerometer. A gravity meter in which a column of mercury is mounted axially on a motor-driven shaft with a fluid-pressure accelerometer at its outer end, the ac output of the accelerometer being indicated.

MAGNETIC PROSPECTING

U. S. No. 2,648,042. N. E. Klein and J. W. Wright. Iss. 8/4/53. App. 7/6/44. Assign. U. S. A.

Orientation System. A magnetic orientation system having a gimbal suspension mounted on a third axis with pick-up coils on the outer gimbal ring whose signal is balanced against the signal from other pick-up coils which control the orientation about the third axis.

U. S. No. 2,648,046. R. A. Wallauschek. Iss. 8/4/53. App. 9/27/49 and 9/14/50.

Piezoelectric Magnetometer. A magnetometer having two oscillating piezoelectric crystals in series and a conducting loop around each of them, the loops being connected in series to add their induced voltages due to change in area of the loops as the crystals oscillate.

U. S. No. 2,649,568. E. P. Felch, Jr. and F. G. Merrill. Iss. 8/18/53. App. 7/12/49. Assign. Bell Telephone Laboratories, Inc.

Magnetometer. A saturable-core magnetic pick-up with a core having a sensing gap and a center-tapped winding whose two parts are excited past saturation in opposite senses and connected to transformers so as to indicate the unbalance due to the picked-up field.

* Gulf Oil Corporation, Patent Department, Pittsburgh, Pa.

U. S. No. 2,649,569. G. L. Pearson. Iss. 8/18/53. App. 9/28/50. Assign. Bell Telephone Laboratories, Inc.

Semiconductor Magnetoresistive Device. A magnetoresistive magnetometer having a single crystal of germanium whose resistance variations are observed in a bridge circuit.

SEISMIC PROSPECTING

U. S. No. 2,648,055. N. J. Smith and R. I. Smith. Iss. 8/4/53. App. 7/11/51.

Apparatus for Detecting and Recording Measurements of Seismic, Gravitational, and Other Forces. For abstract see Gravimetric Prospecting.

U. S. No. 2,648,979. J. R. Cornett. Iss. 8/18/53. App. 8/9/46. Assign. Seismograph Service Corp.

Transducer Testing Apparatus. A testing apparatus in which the device is driven by a variable-frequency voltage source through a decoupling network and the voltage across the device is compared with that of a standard at various frequencies on a c-r oscilloscope.

U. S. No. 2,649,579. W. A. Alexander. Iss. 8/18/53. App. 2/1/50. Assign. Standard Oil Development Co.

Detector for Seismic Exploration. A capacity-type seismometer which covers a large ground area and having two flat plates separated by sponge rubber or air under pressure and flat masses on the upper side of the assembly.

U. S. No. 2,650,991. R. W. Ketchledge. Iss. 9/1/53. App. 11/14/47. Assign. Bell Telephone Laboratories, Inc.

Accelerometer. For abstract see Gravimetric Prospecting.

U. S. No. 2,651,769. J. A. Stafford. Iss. 9/8/53. App. 8/1/52. Assign. Century Geophysical Corp.

Seismic Vibration Detector. A moving coil electromagnetic seismometer also having a fixed coil wound around the outside of the pole piece and coupled to the moving coil through a condenser to balance pick-up from external interference.

U. S. No. 2,652,550. C. C. Lash. Iss. 9/15/53. App. 2/23/49. Assign. Stanolind Oil and Gas Co.

Marine Seismometer Spread. A marine seismometer spread whose cable, seismometers, and floats are arranged to have neutral buoyancy and having spaced surface floats with suspended weights to which the spread is attached so that the seismometers are maintained at the desired depth.

U. S. No. 2,653,302. W-W. von Wittern. Iss. 9/22/53. App. 10/10/50.

Accelerometer Pickup of Very Small Size and Weight. A variable air-gap reluctance type accelerometer having a small movable magnetic vane which changes the coupling between two coils of an r-f transformer.

U. S. No. 2,653,305. E. L. De Shazo, Jr. Iss. 9/22/53. App. 6/10/49. Assign. Phillips Petroleum Co.

Method of and Apparatus for Measuring the Polarity of Seismometers. A method of checking the polarity of seismometers by deflecting the coil with dc and observing how the impedance changes.

U. S. No. 2,653,306. R. G. Piety. Iss. 9/22/53. App. 10/3/49. Assign. Phillips Petroleum Co.

Seismometer. A condenser-type seismometer having a coarse helical thread machined on the inside of the case and a central insulated helical plate or thread which meshes with the helix on the case and is spaced from it by a spring suspension.

U. S. No. 2,654,077. K. W. McLoad. Iss. 9/29/53. App. 4/6/50. Assign. Socony-Vacuum Oil Co., Inc.

Multiterminal Seismic Cable Connector System. A geophone cable connector system in which the

cable has jacks of different diameters molded into it and streamlined into the jacket so that they are not damaged as the cable is dragged on the ground.

WELL LOGGING

U. S. No. 2,644,891. G. Herzog. Iss. 7/7/53. App. 3/28/50. Assign. The Texas Co.

Method of Neutron Borehole Logging. A neutron-gamma ray logging method using a radioactive source of neutrons and gamma rays and a proportional counter as a detector and separating the larger pulses due to induced gamma rays from the smaller pulses due to scattered gamma rays.

U. S. No. 2,645,723. R. E. Fearon. Iss. 7/14/53. App. 2/21/46. Assign. Well Surveys, Inc.

Method and Apparatus for Increasing Speed of Well Logging. An ionization-chamber circuit in which a second resistor is connected in series with the high resistance and a balancing current applied to the second resistor so as to operate the ionization chamber at constant potential.

U. S. No. 2,646,680. B. R. Steele and W. E. Nolan. Iss. 7/28/53. App. 12/19/47.

Device for Indicating Conditions in Well Bores. A bottom-hole pressure gauge or thermometer which is carried on the lower end of the tubing with one electrical connection made by the tubing and the other made by a spring contact to the casing, the tubing being insulated from the casing by insulating spacers.

U. S. No. 2,648,012. S. A. Scherbatskoy. Iss. 8/4/53. App. 10/5/49. Assign. Perforating Guns Atlas Corp.

Nuclear Well Logging. A radioactivity logging system using a neutron-emitting source and a scintillation counter detector with an anthracene crystal surrounded by boron except for a window of polonium, the pulses from the photomultiplier being selected as to magnitude, automatically corrected for temperature variations, and recorded as indicating gamma rays, fast neutrons, and slow neutrons.

U. S. No. 2,648,056. J. J. Jakosky. Iss. 8/4/53. App. 11/1/48. Assign. Union Oil Co. of Calif.

Well Logging Method and Apparatus. A sonic pulse-echo well-calipering system in which the sonic velocity in the ambient fluid is determined by observing the reflection time from a fixed reflector on the apparatus as well as the reflection time from the wall of the hole.

U. S. No. 2,648,778. D. Silverman, G. R. Newton, and J. E. Skinner. Iss. 8/11/53. App. 12/30/50. Assign. Stanolind Oil and Gas Co.

Automatic Diameter Compensation in Radiation Well Logging. A radioactivity logging instrument which automatically corrects for variations in hole diameter by having a spring-actuated caliper arm adjust a shield between the source and detector or adjust the spacing of an auxiliary source.

U. S. No. 2,648,780. G. Herzog. Iss. 8/11/53. App. 6/15/50. Assign. The Texas Co.

Combination Induced and Scattered Gamma Ray Borehole Logging. A radioactivity logging apparatus having a neutron source and an associated shielded gamma-ray detector and also having a gamma-ray source and associated gamma-ray detector with the two units being separated by at least six feet to prevent interference.

U. S. No. 2,649,710. C. R. Dale. Iss. 8/25/53. App. 12/13/48.

Oil Well Flowmeter. A turbine-type well flowmeter having an upwardly-cupped trap to direct downward flow into the turbine and an expansible downwardly-cupped trap to direct upward flow into the turbine but which when retracted does not impede downward motion of the device in the well.

U. S. No. 2,649,711. C. R. Dale. Iss. 8/25/53. App. 12/13/48.

Apparatus for Determining Fluid Flow in Wells. A well flowmeter having retractable fingers with attached vanes which when released form a trap for directing fluid flow into the metering element.

U. S. No. 2,649,712. C. R. Dale. Iss. 8/25/53. App. 10/6/47.

Oil Well Flowmeter. A turbine-type well flowmeter in which the rotor carries a magnet which actuates a magnetic switch in a lamp circuit and the intermittent illumination is recorded on a photographic tape.

U. S. No. 2,649,715. R. W. Goble. Iss. 8/25/53. App. 5/8/47 Assign. Eastman Oil Well Survey Co.

Temperature Measuring and Indicating Apparatus. A recording thermometer whose sensitive element is a thermistor in a bridge circuit having range-changing resistors in one arm and in the indicating circuit.

U. S. No. 2,649,786. R. W. Goble. Iss. 8/25/53. App. 4/1/48. Assign. Eastman Oil Well Survey Co.

Well Bore Caliper Having Linear Electrical Response. A caliper logging apparatus in which the caliper arms move the core of a solenoid connected in an oscillator circuit whose output is transmitted to the surface by a cable and the frequency recorded.

U. S. No. 2,650.067. P. W. Martin. Iss. 8/25/53. App. 12/13/48.

Apparatus for Logging Wells while Drilling. An electric logging system for use while drilling and having the bit insulated from the drill stem and a contactor which is lowered through the drill stem on a cable, various positions of the contactor permitting observation of maximum and minimum resistance and resistance of the formation being drilled.

U. S. No. 2,651,027. C. B. Vogel. Iss. 9/1/53. App. 10/1/49. Assign. Shell Development Co.

Well Logging. An interval velocity logging apparatus in which a spark discharge through liquid is used to produce an acoustic impulse which is detected at some distance and the amplified received waves observed on a c-r tube screen.

U. S. No. 2,651,370. J. M. Pearson. Iss. 9/8/53. App. 4/24/47. Assign. Sun Oil Co.

Borehole Flowmeter. A well flowmeter in which the metering unit operates a striker whose vibrations are carried to the surface by a supporting rod and detected and counted at the surface.

U. S. No. 2,652,496. G. Herzog and A. S. McKay. Iss. 9/15/53. App. 3/28/50. Assign. The Texas Co.

Radioactivity Method and Apparatus for Borehole Logging. A radioactivity logging apparatus having a flexible sheath around the apparatus housing filled with a non-hydrogenous liquid to displace surrounding well fluid.

U. S. No. 2,652,720. R. G. Piety. Iss. 9/22/53. App. 11/15/48. Assign. Phillips Petroleum Co.

Method of and Apparatus for Determining Total Flow in a Borehole. A well flowmeter having a motor and pump which may be electrically operated to increase the flow by a known amount in order to determine the ratio between total flow and flow through the meter.

U. S. No. 2,652,721. F. L. McMillan and B. F. Wiley. Iss. 9/22/53. App. 2/18/49. Assign. Phillips Petroleum Co.

Thermal Flowmeter. A well flowmeter having a heating coil and a temperature indicator which is compensated for changes in ambient temperature.

U. S. No. 2,653,294. F. L. McMillan, Jr. Iss. 9/22/53. App. 4/21/49. Assign. Phillips Petroleum Co.

Apparatus for Electrical Well Logging. An electrode assembly for electric logging having spherical metal electrodes screwed together by sections of insulating pipe.

U. S. No. 2,653,389. G. J. Butterworth and E. T. Young. Iss. 9/29/53. App. 5/3/48. Assign. Sperry-Sun Well Surveying Co.

Well Surveying Instrument. A well-surveying device having a buoyant pendulum which floats so that an upper pivot rests in a socket and three colinear points at its lower end for making an electrolytic record, a permanent magnet being mounted part way up the pendulum to provide azimuthal orientation of the three points.

U. S. No. 2,653,990. A. A. Brant. Iss. 9/29/53. App. 3/21/51. Assign. Newmont Mining Corp.

Apparatus for Use in Making Geophysical Explorations. A tubing arrangement for pushing electric logging electrodes and cable into a drill hole, the sections of tubing being slotted through the entire length so that the cable may be slipped through the slot as additional lengths of tubing are added.

U. S. No. 2,654,064. R. A. Broding. Iss. 9/29/53. App. 8/28/50. Assign. Socony-Vacuum Oil Co., Inc.

Electrical Resistivity Logging of Mud Invaded Formations. An electrical logging system using a single current electrode with a series of potential electrodes at different distances and a rotating switch which sequentially contacts the various potential electrodes so that the recorded potential is a curve of resistivity variation with increasing electrode spacing.

MISCELLANEOUS

U. S. No. 2,641,924. P. P. Reichertz. Iss. 6/16/53. App. 9/11/47. Assign. Socony-Vacuum Oil Co., Inc.

Determination of Effective Porosity of Core Samples. A method of determining the size distribution of pores in a core sample by immersing the core in mercury whose pressure is progressively increased and measuring the change in total volume effected by the entrance of mercury into the pores.

U. S. No. 2,645,752. C. R. Glanville, H. F. Dunlap, and E. W. Shuler, Jr. Iss. 7/14/53. App. 3/9/51. Assign. The Atlantic Refining Co.

Method and Apparatus for Determining Characteristics of Earth Formations. A method of determining the formation factor of drill cuttings by embedding them in an insulating plastic wafer with two faces of the cuttings exposed and measuring the thickness and electrical resistance of the wafer and the cross-sectional area of the embedded cuttings.

U. S. No. 2,647,323. F. L. Johnson and F. M. Mayes. Iss. 8/4/53. App. 9/26/47. Assign. Sun Oil Co.

Elevation Meter. A vehicle-transported elevation-difference meter in which a pendulum is maintained statistically perpendicular to the path and its torque is multiplied by the increment of path length and the product integrated.

U. S. No. 2,648,781. G. Herzog and R. P. Mazzagatti. Iss. 8/11/53. App. 6/16/50. Assign. The Texas Co.

Detection and Measurement of Radiation. A Geiger-Mueller counter having a series of parallel cathode plates with anode wires passing through holes in the plates.

U. S. No. 2,648.828. C. F. Teichmann. Iss. 8/11/53. App. 4/13/49. Assign. Texaco Development Corp.

Microphone. A microphone for a sonic fluid-level meter having a rubber diaphragm which carries a wire strain gauge whose resistance variations are detected.

U. S. No. 2,649,781. D. H. Clewell. Iss. 8/25/53. App. 9/3/47. Assign. Socony-Vacuum Oil Co., Inc.

Automatic Mapping System. An automatic vehicle position plotter in which a compass reading controls azimuthal direction and a wheel is moved in proportion to distance traversed so that the position is plotted as a polar-coordinate chart.

U. S. No. 2,652,531. W. M. Schaufelberger, H. N. Herrick and J. R. Leggett. Iss. 9/15/53. App. 9/12/49. Assign. California Research Corp.

Apparatus for Determining Magnetic Properties of Well Cores. A magnetic core orienting apparatus in which the core is rotated close to a cathode-ray tube having a pair of plates between which the beam current is divided, the variation in beam current distribution with azimuthal position of the core being observed.

U. S. Nos. 2,652,558–561. J. E. Hawkins. Iss. 9/15/53. App. 1/12/50 and 11/6/51. Assign. Seismograph Service Corp.

Radio Location System. Radio location systems of the hyperbolic, continuous-wave type employing phase comparison in pairs of position indicating signals radiated from spaced transmitters at known locations.

U. S. No. 2,652,562. J. E. Hawkins. Iss. 9/15/53. App. 11/20/51. Assign. Seismograph Service Corp.

Radio Location System. A combined pulse-transit-time and phase-comparison radio-locating system in which two fixed transmitters radiate pulses and a third fixed transmitter radiates c-w and the receiver compares phase between the received c-w and a local signal which is pulse synchronized.

SELECTED LIST OF U. S. PATENTS ISSUED DURING THE THIRD QUARTER OF 1953

Patent No.	*Subject**	*Patent No.*	*Subject**	*Patent No.*	*Subject**
2,644,242	520, 192	2,645,683	484	2,647,162	484
2,644,243	216	2,645,722	308	2,647,167	224
2,644,329	412	2,645,723[a]	304	2,647,168	224
2,644,336	288	2,645,728	380	2,647,236	68
2,644,519	48	2,645,752[a]	88	2,647,256	316
2,644,738	324	2,645,769	316	2,647,323	444
2,644,856	224	2,645,938	140	2,647,395	412
2,644,891[a]	304	2,645,942	16	2,647,401	148
2,644,901	4	2,646,218	12	2,647,402	148
2,644,920	228	2,646,530	316	2,647,403	148
2,644,921	228	2,646,546	160	2,647,406	200
2,644,940	316	2,646,559	320	2,647,750	224
2,644,941	16	2,646,561	316	2,647,813	324
2,645,027[a]	44	2,646,562	316	2,647,945	324
2,645,030	192	2,646,563	316	2,647,948	12
2,645,119	428	2,646,564	312	2,647,949	12
2,645,121	448	2,646,566	316	2,647,954	224
2,645,123	148	2,646,680[a]	288, 460	2,648,008	236
2,645,124	148	2,464,682	288, 444	2,648,009	236
2,645,125	200	2,646,683	288	2,648,010	196
2,645,126	460	2,646,716	428	2,648,011	416
2,645,128	288	2,646,924	16, 68	2,648,012[a]	304
2,645,181	136	2,646,925	68	2,648,014	276
2,645,270	224	2,646,946	16	2,648,015	308
2,645,341	228	2,646,947	16	2,648,041	16
2,645,494	224	2,646,950	436	2,648,042[a]	232
2,645,552	160	2,646,989	224	2,648,046[a]	232
2,645,682	224	2,647,033	324	2,648,055[a]	376, 180

* A key to the subject classification system will be found in GEOPHYSICS, v. 12, p. 256–264 (April, 1947).

[a] Abstracted on preceding pages of this issue.

Patent No.	*Subject*
2,648,056[a]	8
2,648,058	200
2,648,062	316
2,648,133	200
2,648,141	520
2,648,224	148, 460
2,648,435	228
2,648,589	224
2,648,590	224
2,648,778[a]	304
2,648,779	196
2,648,780[a]	304
2,648,781[a]	308
2,648,828[a]	408
2,648,838	16, 312
2,648,976	168, 460
2,648,977	288
2,648,979[a]	380
2,648,981	148
2,648,982	200
2,649,046	136
2,649,163	8
2,649,264	16
2,649,506	224
2,649,550	140
2,649,554	308
2,649,568[a]	232, 224
2,649,569[a]	232
2,649,579[a]	376
2,649,581	316
2,649,707	188
2,649,710[a]	144, 148
2,649,711[a]	148, 144
2,649,712[a]	148, 144
2,649,714	200
2,649,715[a]	460, 452
2,649,781[a]	444
2,649,786[a]	44
2,650,067[a]	208
2,650,068	80
2,650,069	80
2,650,306	236
2,650,307	196
2,650,344	228
2,650,348	160
2,650,359	312
2,650,432	428
2,650,496	148
2,650,539	136
2,650,540	136
2,650,561	148
2,650,760	68
2,650,952	224
2,650,954	484
2,650,991[a]	4, 180
2,651,012	12
2,651,027[a]	8
2,651,148	12
2,651,196	428
2,651,200	200
2,651,201	188
2,651,204	288
2,651,370[a]	148
2,651,459	68
2,651,723	236
2,651,726	308
2,651,756	160
2,651,762	484
2,651,769[a]	376
2,651,774	316
S.N. 657,933	316
2,651,846	140
2,651,848	444
2,651,938	200
2,651,939	200
2,651,940	200
2,651,941	188
2,652,194	68
2,652,195	68
2,652,204	224
2,652,232	80
2,652,260	484
2,652,315	168
2,652,495	236
2,652,496[a]	304
2,652,497	460
2,652,499	308
2,652,530[a]	132
2,652,531[a]	84
2,652,533	232
2,652,542	12
2,652,543	12
2,652,550[a]	360
2,652,554	68
2,652,558-562[a]	312
2,652,720[a]	148
2,652,721[a]	148
2,652,723	16, 148
2,652,727	288
2,652,742	416
2,652,977	68
2,652,979	16, 312
2,653,189	484
2,653,220[a]	132
2,653,232	316
2,653,247	140
2,653,294[a]	116
2,653,295	288
2,653,302[a]	4
2,653,305[a]	376
2,653,306[a]	376
2,653,307	16
2,653,312	316
2,653,313	316
2,653,389[a]	520
2,653,471	168
2,653,477	200
2,653,478	200
2,653,479	200
2,653,761	68
2,653,819	224
2,653,983	460
2,653,990[a]	116
2,654,003	224
2,654,041	308
2,654,060	428
2,654,064[a]	116
2,654,077[a]	360, 40
2,654,083	316
2,654,084	312
2,654,085	316

REVIEWS

REVIEWS COMMITTEE

NELSON C. STEENLAND, *Chairman*, Gravity Meter Exploration Co., Houston
KEITH R. BEEMAN, Southwestern Industrial Electronics Co., Houston
W. T. BORN, Amerada Petroleum Corporation, Tulsa
T. A. ELKINS, Gulf Research & Development Co., Pittsburgh
R. A. GEYER, Humble Oil & Refining Co., Houston
E. G. LEONARDON, Schlumberger Well Surveying Corp., Houston
F. A. VAN MELLE, Shell Oil Co., Houston
PAUL C. WUENSCHEL, Research Incorporated, Dallas
W. JACQUE YOST, Magnolia Petroleum Co., Dallas

CONTENTS

Clay Mineralogy, Ralph E. Grim, by *C. Meade Patterson* 163

A Study of Well Velocity Data in Northwest Germany, W. von zur Muhlen and G. Tuchel, by *L. Y. Faust* 164

Freiberger Forschungshefte, Beihefte Der Zeitschrift *Bergakademie*, by *Richard A. Geyer* 166

Submerged Lands Productive Capacity, National Petroleum Council, by *Nelson C. Steenland* .. 167

Possibilities of Constructing True Ray Paths in Reflection Seismic Interpretation, H. Durbaum, by *F. A. Van Melle* 167

Changes of Ferromagnetic Minerals and Their Bearing on Magnetic Properties of Rocks, John W. Graham, Jr., by *L. L. Nettleton* 168

The Rigidity of the Earth's Inner Core, K. E. Bullen, by *Jack Oliver* 169

Die Aufnahme von Neutronendiagrammen im Bohrlock und ihre Anwendung zur quantitaven Ermittlung der Porositat, Dr. Ing. E. Blum, by *E. G. Leonardon* 169

Clay Mineralogy, Ralph E. Grim, McGraw-Hill Book Company, Inc., New York, 1953, 384 pp., $9.00.

Probably no other phase of mineralogy can claim more recent advances that those made in the study of clays. Only a dawning recognition of clay mineral concepts existed thirty years ago. Since then, growing economic interest in clay materials has fostered productive research which advantageously used new tools and techniques shortly after their introduction. This well organized text testifies to the advanced state of present-day clay mineralogy. Most, if not all, clay mineral groups have been recognized and their likely atomic structures conceived. Physical and chemical properties are sufficiently well known to provide a workable understanding. Insight into clay origin and occurrence has promoted understanding of diagenesis, petroleum formation, and soil processes.

This book deals strictly with clay minerals and their properties. Bulk properties, such as strength, plasticity, and swelling, are only inferred by reference to adsorption, hydration, and lattice expansion of the fundamental clay unit. It may be disappointing to some that there is no discussion of the control of heaving shales, the gelling properties of bentonitic drilling muds, and the stabilizing of reservoir clays. The behavior of the clay mineral, and not that of its aggregate, is the subject of this book. Understanding the various clay minerals at the level of their unit cells, with the expert assistance of Professor Grim's *Clay Mineralogy*, promotes an appreciation of mass properties whether in nature or in industrial processes.

The vast literature of clay mineralogy is widely scattered through domestic and foreign publications in the fields of geology, mineralogy, chemistry, physics, ceramics, soil science and engineering. Now, however, even the research worker, who desires primary sources, will find that the most important references have been listed by Professor Grim. Not until *Clay Mineralogy* was written had

so much up-to-date information been assembled and organized into a single volume where it is readily accessible to all.

After defining terms, the author summarizes the effects of clay minerals, mineral impurities, organic material, exchangeable ions, soluble salts, and texture upon clay materials. Early misconceptions are reviewed before tracing the development of the present-day clay-mineral concept. X-ray diffraction and differential thermal analysis have made major contributions. The two- and three-layer lattice classification is subdivided into equidimensional and elongate forms. Vermiculite is classified with montmorillonite as a clay having an expanding lattice. Chlorite clay minerals are regarded as a separate mixed-layer group. The chain-structure clay minerals (attapulgite, sepiolite and palygorskite) constitute another division. Clay-mineral nomenclature, which has been very confusing, is clarified for the principal varieties. Use of qualifying adjectives expressing degree of hydration is recommended for halloysite. Questionable and discredited clay minerals are proposed for elimination.

The atomic structures are illustrated and described, with appropriate consideration given to structural units, cell and ionic dimensions, structural formulas, layer charges and compositions, and isomorphous substitution. X-ray diffraction data[1] and excellent electron micrographs have been assembled on all clay minerals. Reliable chemical analyses are published in the appendix. Cation exchange, with reference to exchange capacity, structural explanations, exchange positions, effects of particle size, grinding and temperature, replaceability, fixation and determination, receives special attention. Anion exchange is explained as either a replacement of lattice OH groups or an extension of SiO_4 sheets by marginal additions of analogous tetrahedral groups (PO_4 for example).

Pore water and interlayer water (channel or zeolitic water of sepiolite-attapulgite-palygorskite) are described under "Clay-Water System" where the layered configuration of adsorbed water, effects of the exchangeable cation on hydration, stepwise hydration of montmorillonite, and heat of wetting are explained. Although the clay-water system deals only with pore and interlayer water, lattice (hydroxyl) water also enters the discussion of dehydration, the basis for such important methods of clay analysis as vapor pressure determinations, dehydration measurements, and differential thermal analyses. Many thermograms of clay minerals are illustrated as references. An interpretive section for each of the clay minerals accounts for characteristic peaks by water losses, lattice disruptions and phase changes.

Clay-organic complexes are discussed from the structural standpoint of the layer lattice and the adsorbed organic cation. Practical application of synthetic complexes, especially in X-ray diffraction and staining tests, assists in clay mineral identifications. Optical properties, solubility, infrared adsorption, surface area, and density measurements conclude the section on properties and their determinations. Clay mineral synthesis, hydrothermal (argillic) alteration in ore deposits, weathering and soil formation, soil types, and clay minerals in recent and ancient sediments summarize present knowledge on the origin and occurrence of clay minerals. Finally bentonite, aluminous and ferruginous clays, halloysite, and supergene kaolinite are specially considered as unusual clay minerals.

This excellent book condenses modern clay science. Geophysicists would ordinarily not be interested in *Clay Mineralogy* unless prompted by a geological and mineralogical background. Electrical and radioactivity well logging seem to be the only geophysical exploration methods that might be aided by an understanding of modern clay concepts. Cation exchange capacity affects the electrical well log in the expected order of degree: montmorillonite>illite>kaolinite; also, retention of radioactive ions in exchange positions may be recorded by the radioactive well log.

C. MEADE PATTERSON
Gulf Research and Development Co.
Pittsburgh, Penna.

[1] Lattice spacings of X-ray diffraction data are usually in *kX* units whereas the more familiar angstrom units are used in discussing the dimensions of ions and lattice structures. Å = 1.00202 *kX* is the simple conversion factor indicating that units can practically be regarded as interchangeable.

A Study of Well Velocity Data in Northwest Germany, W. von zur Mühlen and G. Tuchel, *Geophysical Prospecting*, Vol. I, No. 3, Sept. 1953, pp. 159–170.

This paper describes a study of the variation of velocity with depth, age, and lithology in 74 conventional velocity surveys in Northwest Germany. The conclusion is reached that depth of overburden is the dominant influence on velocity in sediments of Eocene to Cretaceous age, with lithology the dominant variable in older (Jurassic and Triassic) sediments. The authors also conclude that an increase in lime content increases not only the velocity, but also, and surprisingly, the velocity gradient.

Data on Paleocene and Lower Eocene rocks, described as predominately shales, are taken over 200 meter intervals in a depth range from 350 meters to 1,000 meters. Lower Cretaceous velocity measurements are shown for intervals varying from 80 meters to 250 meters. This section, mainly shales, varies in depth from the near-surface to 1,700 meters. The values of velocity check those reported in North America for similar ages within a reasonable limit of error. However, the velocities at shallow depths are about 200 meters per second lower than those reported in North America while at the greatest controlled depths for the Lower Cretaceous the German values are about 200 meters per second higher than North American. The German data indicate a rapid increase in velocity from 500 meters to about 1,500 meters but with a lower velocity gradient, approaching zero, between the surface and 500 meters.

Most of the discussion is concerned with measurements of velocity in the highly calcareous Upper Cretaceous section. A vertical gradient of 1.45 meters per second per meter is reported as compared to 1.0 meters per second per meter for the corresponding interval of Lower Cretaceous shale.

The Cenomanian and Turonian formations contain 75% to 90% lime. Measurements of velocities in these sections, taken over 300-meter intervals, confirm the other measurements taken in the Upper Cretaceous. The velocities in this highly calcareous section are about 2,500 meters per second (8,300 feet per second) for a 300 meter interval beginning at 300 meters in depth, increasing linearly with depth to about 4,900 meters per second (16,000 feet per second) at 2,000 meter depth.

It is contrary to most North American experience to find a section of 75% to 90% Cretaceous limestone buried one thousand feet deep with a velocity of 8,300 feet per second, which is but slightly higher than the corresponding shale values reported.

Judging from the description of the measurement technique, there is a possible source of error which could be especially serious at the shallower depths. Although there is no discussion of the basis for accepting or rejecting data, the statement is made:

"It cannot be denied that some difficulties arose in exact picking out the arrivals on the record to warrant reliable results as required in the consideration of interval velocities."

The authors state that the error is generally confined to beds of lower velocity. Later, in discussing the reasons for neglecting curved path corrections to measurements at shallower depths, they state that the horizontal distance from shot point to the well is usually close to 100 meters and never exceeds 200 meters. These two statements suggest that trouble from casing or cable breaks may have been severe, especially at the shallower depths.

If spurious breaks have affected the validity of the shallow data, these "leads" would result in erroneously high velocities. Moreover, the transition from "lead" to bona fide first arrivals at some greater depth would give an erroneously low velocity. The data from several wells would tend to mask the transition. The data for the Cretaceous seems to exhibit such tendencies. These difficulties may be rectified, in part, without recourse to the original data. If valid travel times are usually obtained below 600 meters, a summation of all time intervals in each well from zero to the depth of a valid time must equal the valid time. This will be true whether or not the intermediate times are erroneous. A complete time-depth curve determined in this manner should be reasonably correct for all depths, except within the interval of erroneous data. This reviewer has applied this method using the interval velocities reported for the Lower Cretaceous. The resulting data were more consistent below 500 meters than the North American data of the same age. The velocity function appears to be the 6.5

root of depth. Regardless of the validity of the shallow data, there appears to be reasonable agreement with North American data both on the form of the velocity function and on the constants.

This paper is a valuable and welcome addition to the scanty literature on velocity studies. In fact it contains such a wealth of potentially useful material that a re-evaluation of the reliable portion of the data seems desirable. The time-depth relationship is insensitive to random variations and should recommend itself for that reason in the determination of a general velocity function. The data showing the increase in velocity as a function of lithology should be very valuable, especially at the greater depths which are presumably less influenced by the possible errors previously mentioned. The difficulties in dealing with a composite section are very considerable, however. More specific data on lithologic changes, such as variations in porosity and electrical resistivity, would be a welcome addition. It is hoped that the suggestions and criticisms contained in this review will serve as aid and encouragement to the authors in the continuation of their studies.

L. Y. FAUST
Amerada Petroleum Corporation
Tulsa, Oklahoma

Freiberger Forschungshefte, Beihefte Der Zeitschrift *Bergakademie*, Series C, #7 Angewandte Naturwissenschaften, April 1953, Academy Press, Berlin.

This special publication of the periodical *Bergakademie* contains articles of interest both to the pure and applied geophysicist, as well as mining engineers and surveyors. Of the ten articles, totaling 103 pages, those that concern themselves specifically with applied geophysical problems include investigations of the relationships between seismic and gravity conditions and tectonic features in Germany, and a description of field and laboratory experiments involving the propagation of ultrasonic waves in rocks. Other types of articles that could be of interest include the use of seismic techniques to detect rock falls in mines and the possible use of hydrostatic precision leveling instruments for surveying purposes.

The article on regional seismology and tectonics of Germany, by W. Sponheuer, serves as an excellent summary of the available information on this subject beginning with the seventeenth century. However, it is more than an historical review in that the quantitative approach to the energy relationships for various types of earthquakes is discussed also in some detail. In addition, the pertinent information is well organized in tabular form and in a series of excellent detailed maps.

The gravity map of Germany compiled by G. Siemens, using a scale of 1:1,500,000, has a five-milligal contour interval showing the Bouguer values that have been calculated from observations made between 1935 and 1940. The average station density is about six for each 120 square kilometers, and a series of well defined positive and negative gravity axes of a regional nature are evident. The general tone of the text as well as of the discussion section, in which eight geologists and geophysicists participated, is reminiscent of that occasioned by other maps of this type. Emphasis is given to the ubiquitous question: "Do the anomalous zones represent intrabasement and/or basement topographic features, or are they associated primarily with variations in density and structural characteristics of the near-surface formations?"

The information presented and the techniques used by W. Buchheim in describing the results of experiments on the propagation of sound waves through rocks are similar to those listed in the bibliography by such active investigators in this field as Hughes and Kegel. The results are very interesting and add to the knowledge of this subject by making available additional data on coal and various saline rock types, including carnallite and Hartz salt. Perhaps the most interesting aspect of this paper is the emphasis that is given to the hysteresis effects on propagation velocities encountered under increasing and decreasing pressure conditions ranging up to about 400 kg/cm^2. The effect on change of velocity with increasing pressure is particularly important in coal. A 60% increase in velocity occurred over a range of only 50 kg/cm^2, as compared with only a 10–15 percent increase for samples of marble, sandstone, and carnallite.

Some of the results presented in this paper are similar to those discussed by H. Baule, which he presented at the Hanover meeting of December 4 and 5, 1952, of the European Association of Exploration Geophysicists, and published in the journal *Geophysical Prospecting*, Volume I, No. 2, June, 1953. However, all his observations were made under atmospheric pressure. Therefore, the velocities obtained in these experiments for the materials used are open to this objection when attempts are made to try to correlate them with *in situ* subsurface velocities for the corresponding sandstones, anhydrite, dolomite, and coal.

The paper by H. Martin on possibilities for the use of hydrostatic leveling principles in equipment for precision surveying is particularly valuable because of the detail in which some of the instruments used in these tests are described using photographs and detailed drawings. In addition, such second order, but nevertheless important, contributing sources of error in this method are discussed, such as fluid oscillations, capillary effects, and the presence of air bubbles in the tubing, as well as the effect of extraneous particles on the surface of the water and on the tip of the detecting screws. In spite of these factors the author claims that the instrument can be read with an accuracy of ± 0.01 mm. It is interesting to note that no reference is made in the bibliography to several papers on this subject that have appeared during the last few years in GEOPHYSICS and in a few geodetic publications.

RICHARD A. GEYER

Submerged Lands Productive Capacity, National Petroleum Council, Washington, D. C., 107 pp., 1953, $1.50.

The National Petroleum Council was created to advise and inform the Secretary of Interior or the Director of the Oil and Gas Division on any petroleum matters on which he requested information. This volume is a report by a committee of the NPC on Submerged Lands Productive Capacity with L. S. Wescoat as Chairman.

The foreword by Wescoat explains that the volume was prepared in response to a request by the Director of the Oil and Gas Division to study problems of discovery, development, and production offshore. Subcommittees were then created to study this problem offshore from California and the Gulf Coast. In January, 1953, when the publication was being prepared, the actual offshore production was 9,000 barrels per day plus 1,500 barrels of condensate and 100 to 135 MCF of natural gas, all of which was produced from the Gulf Coast. It was further stated that the anticipated offshore drilling in the next five years would be within a depth of 60 ft and would therefore be confined to 14,300 square miles of the total of 278,000 square miles of continental shelf. Extrapolating these statistics, the Committee predicted that the next five years should have 200,000 barrels per day and 700 MCF of gas per day added to the present production rate. This additional production would be equally divided between California and the Gulf Coast.

The California area is handled by a subcommittee of approximately 15 who are identified at the beginning of each section. These sections are on geology, costs, general geographical and oceanographic descriptions, drilling, operations, and production. Several salient features: the cost of an offshore seismic crew is $110,000 per month; only one well has been drilled offshore to date (in 28 feet of water); it is expected that production offshore will cost from three to seven times that on land.

Strangely enough, the Gulf Coast section is presented anonymously. The data are presented under four headings: a general description, a rather detailed geologic account, a section on exploration, and a section on development. The costs of geophysical exploration on land and water are compared. Gravity exploration averages 600 stations per month at a cost of $20.00 each on land. On water, stations average 250 per month at a cost of $120.00 per station. The seismic costs are given as $15,000 per month on land and $35,000 to $80,000 per month on water. It is also stated that drilling offshore costs about six times that on land.

NELSON C. STEENLAND

"Possibilities of Constructing True Ray Paths in Reflection Seismic Interpretation," H. Durbaum, *Geophysical Prospecting*, Vol. 1, No. 2, June 1953, pp. 125–139.

This article treats the same subject matter which Dix and Lawlor dealt with in their article, "Computation of Seismic Dips Below an Unconformity" (GEOPHYSICS, April, 1943). The method of attack is essentially the same, but the present article lacks the lucidity of the older presentation. It is not easy to read, partly because there is a profusion of symbols and subscripts, some of which are introduced without explanation.

The well known relation that the apparent speed along the surface is given by the speed of the surface formation divided by the sine of the angle at which the ray reaches the surface, is presented as Tuchel's formula and over three pages are devoted to it. This relation may be found in M. M. Slotnick's article, "On Seismic Computations, etc." (GEOPHYSICS, Vol. 1, page 9, 1936) and in Jakosky's well known text *Exploration Geophysics* (pp. 675–676 of the 2nd edition), just to name a few. It does not require the elaborate proof given in the present article.

The practicing seismologist who needs a guiding theory in connection with problems of interpretation will find the older articles better suited for his purpose, both in the case of the determination of dips below unconformities and in that of the treatment of apparent speeds at the surface.

F. A. VAN MELLE

"Changes of Ferromagnetic Minerals and Their Bearing on Magnetic Properties of Rocks," John W. Graham, Jr., *Journal of Geophysical Research*, Vol. 58, No. 2, pp. 243–260, June, 1953.

In recent years aeromagnetic surveys have shown a number of instances of strong negative anomalies of diabase dikes. A conspicuous example that is readily available is shown by the aeromagnetic map of the Fairfax Quadrangle, Virginia in the chapter on "Aeromagnetic Surveying" by Balsley in the recent book *Advances in Geophysics* edited by H. E. Landsberg. The sharp, elongated, 700-gamma minimum in the northeast corner of the aeromagnetic map (Fig. 10) corresponds with a dike shown by the corresponding geologic map. Measurements of polarization from samples of dikes causing negative anomalies have shown strong inverse polarization. This paper is an attempt to explain this inverse polarization by processes which do not involve the assumption that the earth's field has reversed its direction since the dikes were formed.

Experiments on dike material to determine the nature of the magnetization when specimens are allowed to cool in the earth's present field, were found to be invalid because of changes in the structure of the material which were produced by the heating. This was demonstrated by X-ray diffraction studies. Tests of the coercive force showed that the samples could be demagnetized with steady fields but, when subsequently exposed to alternating current fields, the original magnetization was recovered.

An hypothesis has been advanced to explain the inverse magnetization as due to the presence of two types of magnetic minerals, one of which is maghemite, a magnetic mineral of high coercive force created by low temperature oxidation of magnetite. The hypothesis is outlined in the following quotation from the original paper:

"It is suggested that initially there needs to be but one constituent, A (magnetite) dispersed by the non-magnetic ilmenite; late-stage oxidation reactions selectively create B (maghemite) at the expense of the smaller particles of A, and it is magnetized in the inverse sense by the external fields of the first magnetized component, A, in the manner treated by Neel. The external moment of the sample then later becomes reversed as a result of the demagnetization, in time, of the larger particles of component A. Magnetite grains that are too large to remain as domains for long periods can be expected to demagnetize by forming domain field closure loops within themselves. The smaller size volumes of maghemite with the inverse moment will remain as stable domains with high coercive force. The essential role of the titanium impurity is that it interrupts the individual large grains so that they can behave as an aggregate of independent tiny particles whose fields interact. Similar conditions might equally well have been achieved by impurities other than titanium coming out of high-temperature stable solid solution in the magnetite."

No direct proof or reproduction of the supposed process has been carried out, and it may be impossible because the processes invoked probably are so slow that they take place over periods of geologic time. Also the properties of the maghemite appear to be relatively unknown but no information on them appears to invalidate the hypothesis.

The dikes studied in this paper are from a swarm in Baraga County in the northern peninsula of Michigan. Not all of the dikes in this swarm have inverse magnetization as in some the polarization is "turbulent" with sharp local variations in direction. The paper contains a number of diagrams of the locations of samples across the dikes and corresponding plots of their direction of polarization on the Schmidt equal-area projection. It was shown by studies of the anisotropy of the susceptibility of samples that the "turbulent" magnetization could not be accounted for by movements of the rocks at temperatures below the Curie point. It is suggested that they may represent an intermediate step in the reversal process but explanations are not very satisfactory.

While much remains to be done before a really satisfactory explanation is obtained for the existence of these puzzling inverse magnetizations, it seems that the present paper, together with the considerable background given in the extensive bibliography, points towards processes which do not require that the earth's field has been reversed in past geologic time.

L. L. NETTLETON
Gravity Meter Exploration Co.
Houston, Texas

"The Rigidity of the Earth's Inner Core," K. E. Bullen, *Annali Di Geofisica*, Vol. VI, No. 2, January 1953, pp. 1–10.

In a concise, well written paper, Bullen presents a fine summary and discussion of the evidence for the existence of significant rigidity in the Earth's inner core ($R \sim 1{,}390$ km). His trial hypothesis stating that compressibility and its pressure gradient are independent of chemical composition below 1,000 km combined with certain probable assumptions about other constants, indicates a considerable rigidity for the inner core. Unfortunately, theoretical calculations predict low energy content for the seismic phase *PKJKP*, where *J* is the shear wave through the inner core, so that seismic verification of the rigidity will probably depend upon statistical studies of this phase on many records. A further consideration of the seismic velocity with depth relations of Gutenberg and of Jeffreys, and certain compressibility pressure relations based on quantum mechanics, lead to the lowest likely value for the rigidity of the inner core, 1.5×10^{12} dynes/cm^2. This is about twice the rigidity of steel at atmospheric pressure.

JACK OLIVER
Lamont Geological Observatory
Columbia University

"Die Aufnahme von Neutronendiagrammen im Bohrloch und ihre Anwendung zur quantitaven Ermittlung der Porosität," Dr. Ing. E. Blum, *Erdöl und Kohle*, Hamburg, Germany, March 1953, pp. 133–136.

The article discusses the technique of measurements in boreholes by neutron-gamma and neutron-neutron methods. Even though it is quite condensed, it gives a comprehensive and thorough picture of our knowledge of the matter at the present time. It should be noted that all the references cited by the author are publications in the American geophysical literature.

E. G. LEONARDON

PUBLICATIONS RECEIVED

American Journal of Science, Vol. 251, Nos. 9 & 10 (Sept. & Oct., 1953)
Annales de Geophysique, Vol. 9, No. 3 (July–Sept., 1953)
Annali di Geofisica, Vol. 6, No. 2 (April, 1953)
Boletin de la Asociacion Mexicana de Geologos Petroleros, Vol. 5, No. 7–8 (July–Aug., 1953)
Bulletin of the Geographical Survey Institute (Tokyo), Vol. 3, No. 2–4 (March, 1953)
Bulletin of the Seismological Society of America, Vol. 43, No. 3 (July, 1953)
Butsuri-Tanko (*Geophysical Exploration*), Vol. 6, No. 2 (1953)
Geophysical Digest (Calcutta), Vol. 1, No. 2 (April, 1953)
Deutsches Hydrographisches Institut Jahrbuch, Vol. 6, No. 1 (1953)
Economic Geology, Vol. 48, No. 6 (Sept.–Oct., 1953)
Erdol und Kohle, Vol. 6, Nos. 7, 8 & 9 (July, August & Sept., 1953)
Geophysical Prospecting, Vol. 1, No. 3 (Sept., 1953)
Journal of Geophysical Research, Vol. 58, No. 3 (Sept., 1953)
Quarterly Journal of the Geological Society of London, Vol. 108, Pt. 4 (Sept. 12, 1953)
Revista di Geofisica Applicata, Vol. 14, No. 1 (1953)
Science, Vol. 118, Nos. 3060 through 3070 (Weekly August 21 through October 30, 1953)
Scientific Monthly, Vol. 77, Nos. 2, 3 & 4 (August, (Sept. & Oct., 1953)

DISCUSSIONS AND COMMUNICATIONS

FLYING SAUCERS AND "DOODLEBUGS"

In his book, *Flying Saucers*,[1] Dr. Donald H. Menzel, Professor of Astrophysics at Harvard University, attempts to explode the myth of this phenomenon. The Reviews Committee was asked to bring this volume to the attention of the Society as an example of how fraudulent devices may be exposed by a scientific evaluation of the facts. This is, of course, in reference to the problem of the miracle "doodlebugs" which are constantly being presented to the petroleum industry.

Dr. Menzel is an authority on the principles of optics with special application to interstellar phenomena. He is able to attribute the documented cases of the flying saucers to illusions which result from the passing of light through ice crystals and air lenses; to the Northern Lights, comets, and meteors; to man-made objects such as kites, balloons, planes, search lights; and even to practical jokers. He further establishes the illusory nature of the flying saucer by reviewing similar occurrences throughout history, from biblical times to the newspaper accounts of the scare of 1897.

The two closing chapters review the possibility of a flight to the moon within the foreseeable future and debate the pros and cons of the existence of life on Mars and Venus. Apparently the primary obstacles to a flight to the moon are the sum of five billion dollars and the problem of organizing the earth's scientific talent.

The book is interesting as a well documented collation of the data pertinent to the flying saucer question. The book is not written for enjoyable reading. It is excessively wordy and, as far as its literary qualities go, it is definitely an amateurish effort. As for the conclusions, there are many instances in petroleum exploration where erroneous and costly conclusions have been reached in arguing from the known to the unknown because of the incompleteness of the known facts and because of their incorrect relationships. Two things come to mind. One is contained in the book itself in a direct quotation of the great scientist Thomas A. Edison, who was instrumental in exploding the scare of 1897. During this explanation, Edison correctly described the future airship as a "mechanical contrivance." But he continues by making the absurd prediction that such airships, if constructed, "would be only toys." The second incident is a newspaper item which appeared about the same time as the book *Flying Saucers*. This account briefly described the visit of Field Marshal Montgomery to Canada to inspect a model of a disc-shaped airship which contained within its central area a large gyro. This airship would be capable of reproducing the many characteristics that have been reported about flying saucers. Therefore the question of flying saucers must remain open, but amenable to more authentic solutions after consideration of the evidence presented by Dr. Menzel.

NELSON C. STEENLAND[2]
Gravity Meter Exploration Co.
Houston, Tex.

[1] Published by Harvard University Press, 319 pages, 1953.

[2] Dr. Steenland is Chairman of the Society's Standing Committee on Reviews.

MEMORIAL

WILLIAM NEAL HOSTETTER

William Neal Hostetter died of polio in Casper, Wyoming, on October 19, 1952 after an illness of two weeks.

He was born September 18, 1922, in Denver where he attended elementary and secondary schools. He went to the University of Denver for three years where he was a member of Alpha Kappa Psi fraternity.

He was a veteran of World War II, having attended Stanford University for one year while in the Army. Following this, he served with the Signal Corps in the European Theater.

After his discharge from military service, he attended Colorado School of Mines from which he graduated in 1950. While there he was a member of Beta Theta Pi, Tau Beta Pi, Blue Key, and Sigma Gamma Epsilon fraternities. He belonged to the *Oredigger* sports staff and was very active in intramural sports.

Since graduation he had been employed as a geophysicist by the General Petroleum Company in Casper.

Mr. Hostetter was a member of the American Association of Petroleum Geologists, Society of Exploration Geophysicists, and the Wyoming Geological Association.

Surviving are his wife, Kathryn Ann; two children, Martha Ann and William T. Hostetter, II; his parents, Mr. and Mrs. William Taylor Hostetter of Denver; and two sisters, Mrs. Paul Denes of Sacramento, California, and Lois Hostetter of Denver.

C. W. KERNS

MEMORIAL

ROBERT LEE McLAREN

Robert Lee McLaren died of a heart attack June 29, 1953, at Wichita Falls, Texas. Lee had suffered a serious attack a few years earlier, but continued his activities and maintained his cheerful and friendly disposition until the end.

Lee was born at Clarendon, Texas, January 6, 1901. At the age of seventeen he and his brother, Colin, were adopted by Mr. and Mrs. Ed Sheegog. Mr. Sheegog died in 1924, but Mrs. Sheegog continued to make a home for Lee until her death in 1936. She was a very lovely and gracious woman and was a dominant influence in Lee's early life. In return she received from him devotion and loyalty of the highest order. In 1940, Lee married Mrs. Thelma Fisher Myers and adopted her two children, Thomas Myers McLaren, then aged nine, and Marion Myers McLaren, four years old. Another son, Robert James McLaren, was born of this marriage. Lee was very proud of his family and gave to all of them alike the same great affection that he had received from his adopted mother. All of them survive him. Thomas graduated in geology from the Colorado School of Mines in 1952, and is now in the U. S. Army Combat Engineers.

McLaren attended the University of Oklahoma in 1920–1922 and then trans-

ferred to the Colorado School of Mines. Upon the death of his foster father in 1924 he had to leave college without obtaining his degree. He worked the rest of that year as assistant geologist for Southern Exploration Company at Wichita Falls, Texas. During 1925 and 1926 he did both surface and subsurface geological work for Navarro Oil Company in the Cisco, Texas, district. He joined L. H. Wentz Oil Division in 1927 and was a key man in that organization for four years.

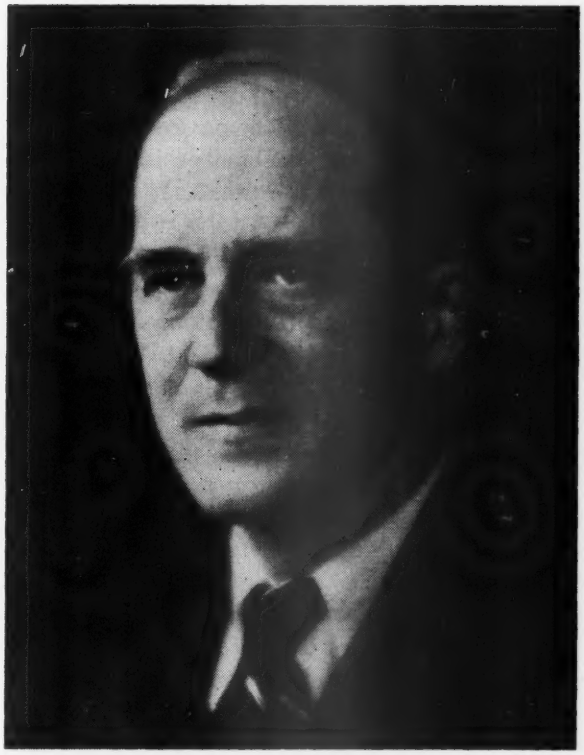
During the 1930–1931 school year Lee returned to Colorado School of Mines and completed his work for the E.M. degree, which was conferred in 1932. He had long been fascinated by the Cripple Creek mining district and leased a mine there in 1931, which he operated with a partner until 1933. This venture returned only modest profits, so he gave it up and did a year of graduate work in geophysics at the Colorado School of Mines. In 1934, he joined the geophysical department of Arkansas Natural Gas Corporation at Shreveport, Louisiana. He became head of the department in 1936 and held that position for eight years.

McLaren formed the Texas Seismograph Company at Wichita Falls, Texas, in 1944. Starting with a single seismograph party and specializing in the North Texas area, he gradually expanded until five parties were in operation. Ashton Crain became a partner in 1945; J. R. Bradley, Jr., and O. B. McReynolds, Jr., joined the company in 1948, and were made partners in 1951. The partners continue to operate the company with his estate as a silent participant.

McLaren was a member of the Society of Exploration Geophysicists, The American Association of Petroleum Geologists, American Institute of Mining and Metallurgical Engineers, Sigma Alpha Epsilon, Theta Tau and maintained an active interest in alumni affairs of the Colorado School of Mines. He was an elder in the First Presbyterian Church of Wichita Falls, Texas.

ASHTON CRAIN

MEMORIAL



MARCEL SCHLUMBERGER

Marcel Schlumberger, 69, Director of Schlumberger Well Surveying Corporation, Houston, and President of Societé de Prospection Electrique and of Compagnie Génerale de Geophysique, Paris, France, died within a few minutes of a heart attack at the Val Richer, the family estate in Normandy, France on August 20, 1953. His death came as a great shock to his family, his friends, and his business associates: his health was excellent, and there was every reason to expect that he would continue for many years the active, leading, and inspiring role which he played in the Schlumberger organization.

Marcel Schlumberger, respectfully called Mr. Marcel by all his associates and co-workers, was born at Guebwiller, Alsace, on June 21, 1884. His native province was then under German domination, and he had to make a choice early in life: either to stay near the family home, serve in the Prussian Army, and become a German subject; or to leave Alsace forever in order to remain a Frenchman. This, like his older brothers, he chose to do.

He received all his education in Paris, graduating as Civil Engineer from the Ecole Centrale des Arts et Manufactures in 1907. He was endowed with remarkable inventive genius, and possessed that resourcefulness, perseverance, and

imagination which make the true inventor. Soon after graduating from Ecole Centrale, he held the position of research engineer or consultant in different companies and industrial organizations, among them Decauville, Charbonnages d'Heraclee, Mines de Bor, Mines d'Ouasta et Mesloula. When World War I came in 1914, he enlisted as a private. Soon he passed examinations to become an officer, and was placed in command of a mobile hospital unit. From there, he was transferred, upon his request, to a French tank unit, and finished the war as a research officer in the technical end of the Tank Corps. For his fine services, he was awarded the Legion of Honor.

After World War I, he became associated with his elder brother Conrad, in developing the new science of electrical prospecting which was then in its theoretical and embryonic stage. For many years the two brothers experienced the hardships that are the lot of precursors. It was next to impossible to sell the French mining industry on a process that seemed very controversial to many. However, success slowly began to crown their efforts, particularly when, after 1927, it became clear that one of their inventions, electrical logging, was a powerful tool for the elucidation of problems of petroleum exploration and production. Already at the death of Conrad Schlumberger in 1936, the reputation of the Schlumberger techniques was established in every oil field of the world. Five years later, in 1941, the A.I.M.E. awarded the Schlumberger brothers (Conrad posthumously) the Anthony F. Lucas Gold Medal for distinguished achievement in the technique of finding and producing petroleum. This high honor was cherished by Marcel Schlumberger for the rest of his life.

Marcel Schlumberger was a member of The American Association of Petroleum Geologists, of the Society of Exploration Geophysicists, of the American Geophysical Union, as well as of numerous French and European scientific associations.

He is survived by his wife, and three children: Pierre Schlumberger, president of Schlumberger Well Surveying Corporation, Mrs. René Seydoux, and Mrs. Paul Primat.

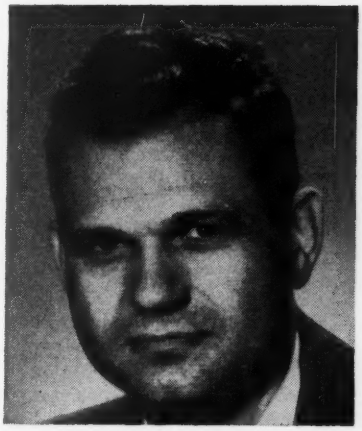
He will be keenly missed among his many friends for his kindness, extraordinary erudition, and sound judgment. His associates and co-workers will long remember him as the outstanding leader that he was: a resourceful and genial hard worker, reluctant to relax as long as a task was unfinished.

EUGENE G. LEONARDON

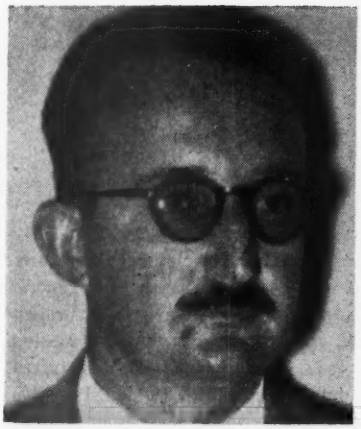
CONTRIBUTORS

GEORGE B. LOPER studied engineering and music at Washburn College in Topeka, Kansas for three years. In 1939, after two years at Kansas University, he received the degree of B.S. in Electrical Engineering. He immediately joined Magnolia Petroleum Company as an Attached Helper in seismic field operations. He served as helper and Junior Observer for one and one-half years, then became Observer on the company's experimental seismograph crew. After four years of experimental and research field operations, he joined the staff of the company's Field Research Department in Dallas working on instrumental development problems in measurement and control. He served as Junior Research Physicist, Research Physicist, and is now Senior Research Technologist working on instrumental problems of detection, recording, and analyzing of seismograph data.

Mr. Loper is a member of Tau Beta Pi, the Institute of Radio Engineers, the Society of Exploration Geophysicists, and the Dallas Geophysical Society.



GEORGE B. LOPER



RODOLFO MARTIN

RODOLFO MARTIN was born in Salta, Argentina, in 1913. He attended the six year course in engineering at the Buenos Aires State University, receiving a degree in 1937. Afterwards, he obtained the title of Geophysical Engineer from the same university. In 1938 he joined the staff of the Y.P.F. Argentine Government Oil Fields geophysical organization, in which he attained the position of chief geophysicist and vice-manager of the exploration department. He taught for two years as professor of applied geophysics at the State university of Eva Perón (until recently La Plata). In the summer of 1953 he left Argentina and became associated with Geophysical Service Inc.

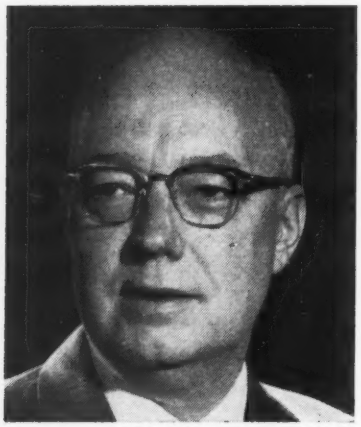
C. H. G. OLDHAM

C. H. G. OLDHAM was born in Yorkshire, England in 1929. He received his undergraduate training at the University of Reading, England, where he received the B.Sc. (General) degree in 1950. He spent a further year at Reading studying geophysics and geology and in 1951 received the B.Sc. (Special) degree with first class honours. He was then awarded a Goldsmiths' Company Post-Graduate Travelling Scholarship which enabled him to visit Canada and study geophysics at the University of Toronto. He received his M.A. at Toronto in 1952 and is now working for the Ph.D. degree under the Department of Physics.

Mr. Oldham is a fellow of the Geological Society of London, and a student member of the Society of Exploration Geophysicsts.

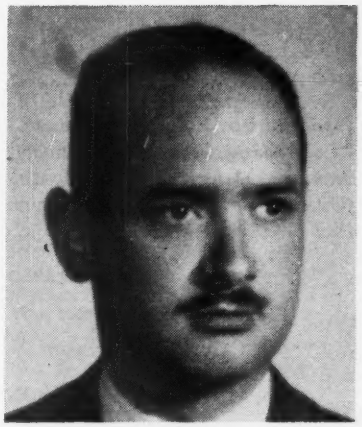
RICHARD A. POHLY

RICHARD A. POHLY attended Albion College and the University of Michigan from 1931 to 1935, where he majored in electrical engineering. This training was later augmented by extension courses in geology and geophysics from The Pennsylvania State College and the University of Texas. In 1937 he was employed by Shell Oil Company in the research division of the geophysical department and since 1941 has been engaged exclusively in gravity work with contract geophysical companies. In 1946, he organized the Global Exploration Company and served as general manager. In 1950, he organized a gravity division for Seismograph Service Corporation and served as manager of the division until April, 1953, when he was elected a vice-president of Seismograph Service Corporation. On November 1, 1953, he formed the Pohly Exploration Co. at Tulsa, Oklahoma. He is a member of the American Geophysical Union, the Society of Exploration Geophysicists, the Tulsa Geological Society, and the American Association for the Advancement of Science.



W. E. WICKERHAM

W. E. WICKERHAM received his B.S. degree in electrical engineering in 1932 from the University of Pittsburgh. He was employed by Gulf Research & Development Company in 1933. Until 1941 he was associated mainly with general geophysical instrumentation. The period 1941 through 1944 was spent doing special weapons instrumentation work at Gulf. Late in 1944, development work was started on an airborne magnetometer suitable for geological surveys and he has been closely associated with and responsible for many improvements in equipment and technique which characterize the present Gulf instrument. He continues in charge of the group on aeromagnetic development. He is a member of the Society of Exploration Geophysicists.

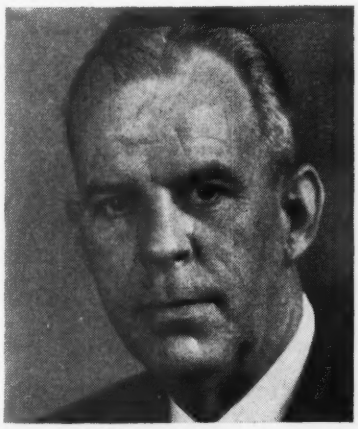


CÉSAR A. TREJO

CÉSAR A. TREJO was born on June 21, 1913 and received the degree of Doctor in Physico-mathematical Sciences (mathematical section) at the National University of La Plata (Argentina) in 1936. From 1936 to 1940 he was an instructor in mathematics and from 1940 to 1948 was an assistant professor at the University of La Plata. During 1948–49 he was professor of mathematics at the University of Cuyo and since 1949 has held this title at the University of La Plata (now University of Perón City). In addition he has been professor of mathematics at the Naval School since 1939.

Dr. Trejo is in charge of mathematical work relating to geophysics in the Y.P.F. (Argentine Government Owned Oil Fields).

He is a member of the American Mathematical Society and is a former vice-president of the Argentine Mathematical Union.



J. RYAN WALKER

J. RYAN WALKER completed requirements for the B.S degree in Mechanical Engineering at the University of Oklahoma early in 1931. After doing some graduate work there he accepted employment with the Geophysical Research Corporation in April 1931. He served that company in various capacities, including Chief Computer, on seismograph field parties until 1937. During 1937, he did record review work and seismic interpretations for the Barnsdall Oil Company. From 1938 to 1942 he served as a seismograph party chief for the Universal Exploration Company, and for the next two and one half years was employed in the same capacity by the National Geophysical Company. He then became associated with the Arkansas Natural Gas Corporation as Seismograph Supervisor, and in September 1946, was named Superintendent of the Geophysical Department. Upon separation, merger, and reorganization of the Arkansas Natural Companies in April 1953, he was named Chief Geophysicist of the Arkansas Fuel Oil Corporation.

Mr. Walker is a member of the Society of Exploration Geophysicists, the Ark-La-Tex Geophysical Society (first Secretary-Treasurer), and the Shreveport Geological Society.

SOCIETY ROUND TABLE

COMMITTEES

Executive Committee, Year Ending 17 April, 1954

President: Roy L. Lay, The Texas Company, Houston, Texas
Vice-President: Karl Dyk, Stanolind Oil & Gas Co., Tulsa, Oklahoma.
Secretary-Treasurer: Bart W. Sorge, United Geophysical Co., Inc., Pasadena, California
Editor: Milton B. Dobrin, Magnolia Petroleum Co., Dallas, Texas
Past President: Curtis H. Johnson, Geophysical Service Inc., Dallas, Texas

Standing Committee on Nominations

Chairman: Roy L. Lay, The Texas Co., Houston, Texas

Curtis H. Johnson — Sigmund Hammer

Standing Committee on Program and Arrangements

Chairman: Karl Dyk, Stanolind Oil & Gas Co., Tulsa, Oklahoma

Richard Brewer	R. W. Dudley	Harold C. Bemis
L. F. Fischer	Arnold Bleyburg	Fred Forward
H. M. Houghton	E. V. McCollum	W. L. Homan
D. R. Dobyns	Reese H. Tucker	R. N. Harding
J. P. Woods	R. G. Piety	G. A. Berg
P. A. Weirich	Milton Born	O. B. Manes
Perry Byerly	R. W. Gemmer	P. E. Narvarte
L. Y. Faust	V. J. Blum	H. O. Seigel
W. Baillie	R. B. Ross	Frank Press
A. van Weelden		E. H. Shannon

Program Subcommittee on Seismic Reflection Quality

Chairman: Paul L. Lyons, Anchor Petroleum Co., Tulsa, Oklahoma

Hugh Thralls	William Erdahl	Glenn Bader
Ben Rummerfield	O. K. Fuller	J. R. Maxey

Standing Committee on Education

Chairman: J. B. Macelwane, S.J., Saint Louis University, St. Louis, Missouri

D. C. Skeels		John C. Hollister
M. King Hubbert	Perry Byerly	Sherwin F. Kelly
Beno Gutenberg		H. W. Straley III

Standing Committee on Distinguished Lectures

Chairman: Paul L. Lyons ('54), Anchor Petroleum Co., Tulsa, Oklahoma

Carl Savit ('55)	Francis F. Campbell ('56)
Peter Dehlinger ('55)	John Ferguson ('56)

Standing Committee on Radio Facilities

Chairman: R. D. Wyckoff, Gulf Research & Development Co., Pittsburgh, Pa.
Vice-Chairman: W. M. Rust, Jr., Humble Oil & Refining Co., Houston, Texas

Bart W. Sorge	C. B. Bazzoni	Daniel Silverman
E. M. Shook	V. Robert Kerr	Richard Brewer
	J. O. Parr, Jr.	

Standing Committee on Membership

Chairman: Carl L. Bryan, Consultant, Shreveport, Louisiana

Francis F. Campbell — J. E. McGee

Standing Committee on Honors and Awards

Chairman: Norman Ricker ('54), The Carter Oil Co., Tulsa, Oklahoma

L. L. Nettleton ('55) — George E. Wagoner ('57)
Andrew Gilmour ('56) — Sigmund Hammer ('58)

Standing Committee on Publications

Chairman: John P. Woods, The Atlantic Refining Co., Dallas, Texas

L. L. Nettleton — Cecil H. Green
M. King Hubbert — Sigmund Hammer

Standing Committee on Reviews

Chairman: N. C. Steenland, Gravity Meter Exploration Co., Houston, Texas

Paul C. Wuenschel — F. A. Van Melle — R. A. Geyer
W. Jacque Yost — E. G. Leonardon — T. A. Elkins
W. T. Born — Keith R. Beeman

Standing Committee on Publicity

Chairman: Weldon B. Hill, Houston, Texas

A. E. Smith — R. H. Andrews — John McCaslin
C. C. O'Boyle

Standing Committee on Public Relations

Chairman: R. C. Dunlap, Jr., Geophysical Service Inc., Dallas, Texas

Edward G. Schempf — A. E. McKay — C. G. Dahm
Wm. P. Ogilvie — E. L. Ricketts — Dale E. Turner
Robert Dyk — Eugene W. Frowe — L. D. Dawson, Jr.
Stanley W. Wilcox — Van A. Petty, Jr. — Lewis Riley
Philip C. Ingalls

Standing Committee on Geophysical Activity

Chairman: Sigmund Hammer, Gulf Research & Development Co., Pittsburgh, Pa.

A. A. Brant — Herbert Hoover, Jr. — Raoul Vajk

Standing Committee on Student Membership

Chairman: Eugene W. Frowe, Robert H. Ray Co., Houston, Texas

Standing Committee on Safety

Chairman: John F. Imle, Geophysical Service Inc., Dallas, Texas

R. A. Weisbrich — Walter E. Jasper — Bart W. Sorge
W. H. Hawkes — W. H. Newton — John W. Green
Frank Searcy

SPECIAL GLOSSARY COMMITTEE
(A. G. I. GLOSSARY SUBCOMMITTEE)

Chairman: RICHARD A. GEYER, Humble Oil & Refining Co., Houston, Texas

GLENN J. BAKER	F. HALE	LEE PARK
JOHN G. BEARD	C. H. HIGHTOWER	FRANK A. ROBERTS
C. HEWITT DIX	JOHN C. HOLLISTER	FRED ROMBERG
	R. L. KISSLINGER	

SPECIAL COMMITTEE ON STUDENT ESSAY CONTEST

Chairman: FRED J. AGNICH, Geophysical Service Inc., Dallas, Texas

JOHN C. HOLLISTER	E. A. PIELEMEIER	H. M. THRALLS
J. B. MACELWANE	M. M. SLOTNICK	J. T. WILSON

SPECIAL COMMITTEE ON BUSINESS OFFICE SURVEY

Chairman: KARL DYK, Stanolind Oil & Gas Co., Tulsa, Oklahoma

PAUL L. LYONS E. V. MCCOLLUM

SPECIAL COMMITTEE ON GEOPHYSICAL CASE HISTORIES VOLUME II

Chairman: D. P. CARLTON, Humble Oil and Refining Company, Houston, Texas

Editor: PAUL L. LYONS, Anchor Petroleum Co., Tulsa, Oklahoma

L. F. ATHY	MILTON DOBRIN	L. L. NETTLETON
A. B. BRYAN	A. J. HINTZE	G. H. WESTBY
K. E. BURG		ROY L. LAY

SPECIAL COMMITTEE ON CONSTITUTION AND BYLAWS

Chairman: W. M. RUST, JR., Humble Oil & Refining Co., Houston, Texas

HENRY C. CORTES	ANDREW GILMOUR	J. J. JAKOSKY
CECIL H. GREEN	SIGMUND HAMMER	L. L. NETTLETON

JOINT A.A.P.G., S.E.G., S.E.P.M. ADVISORY COMMITTEE ON RADIOACTIVE MINERAL EXPLORATION
(S.E.G. MEMBERS)

Vice-Chairman: HENRY C. CORTES, Magnolia Petroleum Co., Dallas, Texas

CECIL H. GREEN SIGMUND HAMMER GERHARD HERZOG GERALD H. WESTBY

DIRECTORS OF THE AMERICAN GEOLOGICAL INSTITUTE

GEORGE E. WAGONER (Nov., 1954) SIGMUND HAMMER (Nov., 1955)

REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY
NATIONAL RESEARCH COUNCIL

L. L. NETTLETON, Gravity Meter Exploration Co., Houston, Texas
(June, 1954)

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the society. This publication does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees he should send it to the president within thirty days. Names of the references appear in parentheses after the name of each nominee.

ACTIVE

René Philippe Bouchon (Léon Migaux, Jacques Le Blanc, A. Roger)
Hiram Craig Boyd (D. P. Carlton, J. E. LaRue, J. B. Hudson)

George Wendell Briggs (C. G. McBurney, R. D. Arnett, C. C. Williams)
Gerald Lee Canfield (A. E. Benson, F. W. Borman, L. Y. Faust)
Everett Eaves (Robert Baum, Paul Stokely, J. C. Menefee)
Thomas Ellis Edward (E. J. P. van der Linden, V. V. Graf, A. A. Fitch)
Wiley Frank Files (W. L. Homan, R. E. Davis, Frank B. Smith)
Kenneth W. Germond (E. A. Krieg, L. E. Nugent, J. W. Horn)
Paul Giraud (Leon Migaux, Jacques, LeBlanc, A. Roger)
Josiah Jernigan Godby (J. P. Woods, Tom Prickett, Jr., E. D. Riggs)
J. A. Hall, Jr. (R. E. Butler, J. W. Fishback, K. D. Kubic)
Glen Robbie Haun (J. L. Burns, D. M. Sargent, T. Rozsa)
Hollis Dow Hedberg (E. A. Eckhardt, Leo J. Peters, T. J. O'Donnell)
Richard Bozman Hohlt (N. J. Smith, H. E. Stommell, J. H. Todd)
Robert Barclay Hollingsworth (C. E. Buffum, E. B. Stover, Jr., N. R. Sparks)
Kenneth N. Houlette (W. A. Hawkes, G. N. Meade, H. A. Willis)
Waldo Emerson Jackson (D. R. Dobyns, John T. Geer, R. M. Nugent)
Richard Wilson Keeling (L. G. Ellis, H. H. Happel, F. F. Reynolds)
Elizabeth Raymond King (Henry R. Joesting, Mary C. Rabbitt, Joel H. Swartz)
Gesa Kunetz (Leon Migaux, Jacques LeBlanc, Lucien Beaufort)
Don G. Lovett (Robert L. Tucker, Albert M. Kimes, Roy F. Bennett)
Jean-Paul Mathiez (Leon Migaux, Raymond Maillet, E. G. Leonardon)
Clarence Richard McKee (R. F. Van Cleave, C. P. Durant, F. M. Hawpe)
Junius Hughes Morrill (W. W. Clark, C. Win Payne, Ed Gemmill)
Austin James Newton, Jr. (W. W. Newton, J. D. Perryman, B. D. Farrow)
Fred Henry Nicolai (L. B. Snedden, D. H. Scott, I. V. Scherb)
Rolf Erdmann Pallat (Carl J. Chapman, Harold W. Stoneman, William Stackler)
Homer Whitman Patnode (Leo J. Peters, Sigmund Hammer, R. B. Ross)
Arthur Franklin Pocock (Maynard Jones, E. V. Dedman, Al Storm)
Morris Grady Spencer (Cecil H. Green, Fred J. Agnich, Kenneth E. Burg)
Lawton Blaine Stephenson (T. L. Allen, P. E. Narvarte, P. J. Rudolph)
Earl Ewing Westmoreland (M. C. Kelsey, E. F. McMullin, J. Frank Rollins)

TRANSFERS TO ACTIVE

Mustafa Aydin (R. LaRue, Wess Robey, Kenneth S. Cohick)
Adrian A. Becker (John M. Crawford, Donald E. Mitchell, James R. Gaebe)
Robert Hugh Bixby (L. F. Athy, H. R. Prescott, B. G. Swan)
Dennis Alvin Bloodworth, Jr. (H. R. Prescott, B. G. Swan, Frank Searcy)
Harold S. Bratlie (J. W. Fishback, K. C. Thompson, Karl Dyk)
Alton O. Burden (C. D. Whitsitt, S. O. Patterson, K. A. Robertson)
Kenneth Carl Coulter (H. J. Kidder, L. Twining, H. F. Rivers, Jr.)
William Wade Crump (Andrew Gilmour, K. M. Lawrence, A. I. Innes)
Richard Q. Foote (R. H. Dana, E. F. Blake, R. E. Davis)
Henry Lowry Grant (Dean Walling, V. E. Prestine, Booth B. Strange)
John Wyeth Green (Walter J. Osterhoudt, Cecil H. Green, Chester J. Donnally)
Kenneth Edward Hunter (A. A. Brant, J. T. Wilson, J. H. Hodgson)
David Franklin Jewell, Jr. (W. O. Novelly, F. E. Brown, W. B. Brinnon)
Stanley Marvin Leventhal (Fred J. Agnich, Cecil H. Green, Earl Thomas)
H. Raymond Livingston (C. H. Hightower, J. V. Franklin, C. G. Faubion)
John Ohman (Wm. M. Rust, Jr., Daniel Silverman, John C. Cook)
William Lee Romine (Flint Agee, L. A. Martin, Walter R. Fillippone)
Robert Edward Sheriff (Francis A. Hale, Joseph W. Northrop, C. Hewitt Dix)
James William Sickles (Dean Walling, V. E. Prestine, Jack M. Desmond)
Thomas D. Trostle (T. P. Ellsworth, Paul E. Swenson, Fred J. Agnich)
George Glenn Vanderdoes (F. F. Reynolds, J. D. Marr, A. A. Hunzicker)
Dwayne R. Witherspoon (Roy L. Lay, Otis B. Hocker, J. S. Welboan, Jr.)

ASSOCIATE

James Henry Alkire (W. M. Tottenham, R. M. Nugent, Klaas van der Weg)
Frank Anthony Angona (J. E. White, M. B. Dobrin, F. J. McDonal)
Henry Robert Bales, Jr. (W. H. Doughty, Sidon Harris, H. B. Mayo)
George Lewis Barnes (Andrew Gilmour, Junius O. Laws, Charles T. Rankin)
Clifford O. Bell (Roy O. Smith, R. H. Dana, Elmer F. Blake)
Hubert Little Bender (Weldon L. Crawford, Clark Bissett, Edward W. Hans)
James Beau Binford (T. R. Shugart, B. D. Farrow, J. D. Perryman)
William Irving Brogden, Jr. (W. H. Doughty, H. B. Mayo, R. H. Dana)
Richard Eugene Brunson (T. O. Hall, Robert R. Singer, Chester Sappington)
Lewis Orr Chubb (Lewis D. Strutzel, Robert H. Ray, Eugene Frowe)
Horace Donovan Cotter (Robert S. Duty, George R. Turner, James H. Rucker)
Emory Eakman Diltz (H. R. Prescott, B. G. Swan, E. L. Mount)
Jay B. Dreves (Roy L. Lay, L. V. S. Roos, Alton McClung)
Lynn Joseph Drury (D. R. Dobyns, John T. Geer, James M. Wilson)
Stacey Eugene Eckert, Jr. (E. V. McCollum, Craig Ferris, Hobart C. Smith)
Rudolph Adolph Eisentraut (F. A. Hale, R. E. Doe, W. E. Bannister)
William LeRoy Field (A. J. Hintze, W. H. Courtier, R. E. Beck)
Edward Ambrose Flinn, III (Cecil H. Green, Patrick M. Hurley, R. R. Shrock)
William George Freitag (W. Hafner, Arne Junger, F. Goldstone)
Thomas A. Garrod (H. G. Mace, E. L. Ricketts, Artemio Maureira)
William Dean Gibbons (L. L. Nettleton, Nelson C. Steenland, John L. Bible)
Morris Fogle Gillett (J. P. Woods, Tom Prickett, H. L. DeFord)
James Edgar Green (H. E. Itten, R. A. Baile, J. R. Hunt)
Richard Norman Gross (Paul F. Clement, Randell B. Carter, A. H. McKee)
Khalifa Arif Hakim (R. D. Holland, F. B. Wallis, C. S. Johnson)
Reginald Newton Harbison (Paul M. Thompson, David H. Scott, R. N. Bruyere)
Ross Allen Harris (W. H. Hawkes, G. V. Dunn, John McKeever)
Clyde Elvis Hendrix, Jr. (Glendon D. Jett, Neal Clayton, Ben F. Rummerfield)
Francis Lawrence Hickey (G. J. Blundun, E. T. Cook, D. V. Bigelow)
Harley Frank Hines (Fred J. Agnich, Curtis H. Johnson, Paul V. Hodge)
Frank George Horino (Willis H. Fenwick, Michael J. Walczak, Wm. Peery)
William Robert Humphrey (Edwin Bartel, H. Dodson, Roland H. Carter)
Donald Charles Jolliffe (Charles B. Smith, Jr., Ben W. Smith, Byron Vorheis)
Ralph Milburn Jones (F. Goldstone, W. Hafner, Arne Junger)
John Albert Kruppenbach (A. E. McKay, C. J. Lomax, C. N. Page)
Royce Rea Latimer (J. R. Cornett, John Monkhouse, R. D. Arnett)
Broadus Edgar Littlefield, Jr. (C. E. Allen, Frederick E. Romberg, Roy Fuller)
Hazel Beatrice McKenzie (Robert E. Doe, F. A. Hale, E. A. Kiesler)
William Marcel Malicoat (D. G. Coppedge, Dearyl E. Pennington, Donald E. Heilner)
Clifford H. Mashburn (Karl Dyk, K. C. Thompson, J. W. Fishback)
Oris Deaderick Massey (A. H. McKee, J. L. Robinson, W. A. Meszaros)
John William Meek (Harry R. Imle, E. J. Gemmill, Leo Konz, Richard H. Hopkins, Richard H. Hagemann)
Robert S. Meyer (R. F. Christy, R. D. Miller, J. B. Macelwane, S. J.)
David Austin Miles (H. E. Shell, T. E. Dennis, C. E. Reel)
Trevor Walter Morrison (L. Tarrant, D. T. Germain-Jones, R. Davies)
Abul Khair Mousuf (Arthur A. Brant, Harold O. Seigel, J. E. Blanchard)
Ralph Windell Nault (R. O. Smith, E. F. Blake, R. H. Dana)
Herbert Hewitt Nuttli (F. Goldstone W. Hafner, J. E. Walker)
Cecil Toney Phillips (Ralph Akin, George E. Wagoner, James P. Duncan)
Charles Edgar Price, Jr. (S. W. Dana, Clyde Mock, O. W. Albert)
Lew Gilliam Schroeder (S. C. Stoneham, P. E. Swenson, T. P. Ellsworth)
Concomly Albert Seafeldt (Dean Walling, V. E. Prestine, J. M. Desmond)

Thomas Dale Sinclair, Jr. (Dean Walling, John A. Adams, Francis G. Bryan)
Luis Hernan Tejada-Flores (R. A. Peterson, B. W. Sorge, N. H. Lago)
Herman Boyd Thomason (Jesse E. Spencer, Leslie C. Spencer, Fred L. Travis)
Jack Hugh Thompson (James E. Thompson, William A. Watson, C. E. Williams)
Alexander Brian Thomson (F. Goldstone, W. Hafner, J. E. Walker)
Glen Anthony Tompkins (Mustafa Aydin, Wm. P. Ogilvie, W. N. Rabey)
Harold J. Trepagnier (Paul F. Clement, William A. Meszaros, A. H. McKee)
John Bowden Venters (H. G. Patrick, R. P. Warren, E. W. Hunt)
Dan Gordon White, Jr. (Thomas J. Bevan, James D. Perryman, H. L. Pullen)

TRANSFERS TO ASSOCIATE

Clifton Orel Greenfield (Carl M. Wert, D. M. Woods, D. W. Roper)
Brian Bernard Hill (J. E. Arceneau, W. R. Gregg, A. M. Eichelberger, Jr.)
Otto William Nuttli (James B. Macelwane, S.J., Victor J. Blum, S.J., Carl Kisslinger)

ANNOUNCEMENTS

PRESIDENT OF ST. LOUIS STUDENT SOCIETY APPOINTED TO CONVENTION COMMITTEE

On accepting appointment to the Information Committee of the 1954 annual joint meeting of A.A.P.G., S.E.G. and S.E.P.M., John J. McCormick, President of the Geophysical Society of St. Louis University reported that this society has adopted a resolution by quorum vote to cooperate in any way possible to insure the success of the meeting. Our St. Louis University Society has already contributed to the meeting by obtaining low-cost hotel accommodations for student delegates. They are also assisting in plans for field trips, provision of technical services, and are planning an extensive educational exhibit on behalf of the Institute of Technologv of St. Louis University.

GEOLOGY TEACHERS HONOR AUGUSTANA PROFESSOR

The Association of Geology Teachers, at its meeting held November 9, 1953, at the Royal York Hotel in Toronto, Canada, named Dr. Fritiof Fryxell, Professor of Geology at Augustana College, Rock Island, Ill., the first medalist of the Neil Miner award of that organization. The Award was established last year to recognize meritorious accomplishment in stimulating interest in the earth sciences.

S.M.U. SEISMOGRAPH STATION OPENS

The Seismological Observatory of Southern Methodist University in Dallas, established through the joint action of the University and The Dallas Geophysical Society, was opened at dedication ceremonies held on December 14, 1953. The newest in the nation's network of earthquake-recording stations, the Observatory is equipped for three-component registration with Benioff seismometers, long and short period photographic recorders for each component, and a visible recorder for the vertical component. All equipment in the Observatory was designed by Professor Hugo Benioff, of the California Institute of Technology, and constructed by the Geotechnical Corporation of Dallas. Prof. Benioff gave the principal address, entitled "Earthquakes," at the dedication ceremonies. Among the other speakers were Roy L. Lay, President of the Society of Exploration Geophysicists, and Dr. Umphrey Lee, President of Southern Methodist University.

A total of $11,500 to equip the Observatory was obtained from thirty-one individuals and organizations in the Dallas area by a Funds-Raising Committee of the Dallas Geophysical Society under the chairmanship of O. C. Clifford, Jr., Atlantic Refining Company. The technical planning was carried on by another committee of the Dallas society under the chairmanship of C. G. Dahm, Hunt Oil Company, who was First Vice-President of the society. The Observatory will be operated by the Physics and Geology Departments of S.M.U. It is located in a vault in the basement of the Fondren Science Building, except for the visible recorder which is in an alcove off the foyer of the same building.

PERSONAL ITEMS

Members of the society are invited to notify the business manager, in care of the society, of any change in their positions or companies for announcement in this section. Members are further invited to check with the public relations departments of their companies to assure that GEOPHYSICS is on their mailing lists to receive publicity releases.

DALLAS R. DAVIS, publicity chairman for the Sixth Annual Institute of Radio Engineers Conference and Electronics Show, advises that geophysicists are quite active in preparations for the event. It will be held at Hotel Tulsa, Tulsa, Oklahoma, on February 4, 5, and 6, 1954. Those serving are: W. T. BORN, General Chairman; C. E. BUFFUM, Vice-Chairman; DANIEL G. EGAN, Secretary-Treasurer; DANIEL SILVERMAN and C. F. HADLEY, technical program; CHARLES E. DAY, arrangements and housing; and GLENN PETERSON, registration. Mrs. Daniel G. Egan is in charge of the ladies' program.

CHESTER SAPPINGTON has been elected chairman of the board of General Geophysical Co. Houston, Texas. He was formerly a vice-president of the firm. T. O. HALL, also a vice-president, has been elected president to succeed the late Earle W. Johnson. KENNETH R. WELLS was elected vice-president, and A. B. GRUBB was reelected secretary-treasurer.

ADRIAN E. MIX, formerly with Ashland Oil and Refining Co. in Shreveport, Louisiana and Billings, Montana, has commenced private practice as a consulting geologist in the Ark-La-Tex area. His office address is 506 Shelby Building, Shreveport, Louisiana.

T. P. ELLSWORTH, formerly division manager of the West Coast division of Geophysical Service Inc., has been appointed sales manager in the GSI marketing department. Mr. Ellsworth has moved from Bakersfield, California, to Dallas, where he will work from the general headquarters of the company at 5900 Lemmon Avenue.

Appointments in the geophysics division of The California Company include R. H. HOWE, northwestern division geophysicist at Bismarck, N. D.; A. L. LYTH, southeastern-eastern division geophysicist at Jackson, Miss.; O. A. POIRIER, offshore geophysicist at New Orleans, La.; E. B. WASSON, western division geophysicist at Denver, Colorado; and R. G. WEGENER, southern (inshore) division geophysicist at New Orleans. The company has established these positions to advise the respective division exploration superintendents on all aspects of geophysical work, including program planning and interpretation, and to supervise the geophysical personnel and work in the field and at division headquarters. J. W. NORTHROP, III, senior geophysicist, will advise the geophysics superintendent and division geophysicists on technical problems, as well as adapt research results to company geophysical operations. He will also direct the geophysics division's central computing work.

CHARLES C. BATES was recently made deputy director of the Division of Oceanography, U. S. Hydrographic Office, in Washington, D. C.

WILLIAM M. BARRET has announced the beginning of construction on a new geophysical plant in Shreveport, Louisiana. To be completed before the end of this year, the new plant will house the administrative offices, laboratories, and instrument shops of Wm. M. Barret, Inc.

HERBERT HOOVER, JR., has been appointed as a special adviser on world-wide petroleum matters to Secretary of State John Foster Dulles. For the past fifteen years Mr. Hoover has been an adviser on technical and economic problems related to oil for various governments including Venezuela, Chile, Peru, Brazil, and Iran.

WILFRED P. HASBROUCK, formerly with Stanolind Oil & Gas Co., is now an instructor in geophysics at Colorado School of Mines, Golden, Colorado.

FRED G. KNIGHT has resigned as District Representative from the Ark-La-Tex Geophysical Society as a result of his transfer to the Jackson, Mississippi office of The Ohio Oil Company. Mr. Knight is also a past president of the Shreveport Section.

A. G. CAAN has accepted an assignment of approximately six months' duration in Germany for Socony-Vacuum Oil Company, Inc.

JAMES ROBERT MOORE, III, has resigned as research geologist from the Standard Oil Company of Ohio, and is now Teaching Fellow in geology in pursuance of doctoral study at Harvard University.

PAUL WEAVER, who recently retired as technical assistant to the vice-president of Gulf Oil Corporation, Houston, will devote part time to teaching seniors and graduate students as a Distinguished Research Geologist on the staff of the Texas A. and M. College. While retaining his residence at 2317 MacConda Lane, Houston, Mr. Weaver will have an office in the Petroleum Engineering building at College Station, Texas, and will spend about half his time there.

JACKSON M. BARTON is now exploration manager of Northern Natural Gas Company's gas supply department. Mr. Barton was formerly manager of the geological department of Deep Rock Oil Corporation in Tulsa, Oklahoma.

WILLIAM G. ALLEN, formerly party chief for Keystone Exploration Company, Houston, Texas, has been promoted to resident supervisor of the company's northwest division, with offices in Billings, Montana.

S. P. WEATHERBY is now seismic supervisor for Donnally Geophysical Co. at Roswell, New Mexico.

RICHARD A. POHLY, formerly vice-president of Seismograph Service Corp., has organized the Pohly Exploration Co., specializing in gravity meter surveys and interpretation. Offices of the new company are at 38th Street and Peoria Ave. in Tulsa, Oklahoma.

DALLAS R. DAVIS has formed the Davis Equipment Co., distributors of geophysical equipment and supplies, at 1231 East 38th Street, Tulsa 5, Oklahoma.

ROBERT W. OLSON, formerly Vice President Research and Engineering, Texas Instruments Incorporated, was elected President of Houston Technical Laboratories on December 3rd following the acquisition of Houston Technical Laboratories by Texas Instruments. Founder and former president SAM P. WORDEN will remain at HTL as Vice-President.

All seismic instrument manufacture now being conducted at Texas Instruments will be transferred to Houston Technical Laboratories. HTL will continue the manufacture of gravity meters and optical components. GALE WHITE will head Seismic Instrument Engineering at HTL and JOHN WEBER will handle Seismic Instrument Sales.

THE DALLAS GEOPHYSICAL SOCIETY has elected the following officers for 1954: C. G. DAHM, Hunt Oil Co., President; J. D. PERRYMAN, The Geotechnical Corporation, First Vice-President; J. A. LESTER, Magnolia Petroleum Company, Second Vice-President; and EDGAR J. STULKEN, Geophysical Service Incorporated, Secretary-Treasurer.

CLARENCE L. MOODY, formerly staff research geologist, Shreveport, Louisiana, and President of the A.A.P.G. in 1950, retired from The Ohio Oil Company on October 31 after completing more than 35 years of service.

A. E. BRAINERD, formerly Rocky Mountain Regional Geologist for Continental Oil Company and DR. F. M. VAN TUYL, for many years head of the Department of Geology at the Colorado School of Mines, announce the opening of offices in Denver and Golden as consultants in Petroleum and Engineering Geology.

The major fields to be covered are petroleum and natural gas, industrial minerals, underground water problems, general geological research, producing and potential property evaluations, and estimates of reserves.

DR. KENNETH L. COOK has been appointed Associate Professor and Head of the Department of Geophysics of the University of Utah, Salt Lake City, Utah. Formerly employed with the U. S. Geological Survey, he will continue his affiliation on a part-time basis with the Geological Survey for research studies in geophysics. Dr. Cook has also been appointed Chairman of the Geophysics Subdivision of the American Institute of Mining and Metallurgical Engineers.

PROPOSED AMENDMENTS TO THE BY-LAWS OF THE SOCIETY

The S.E.G. Executive Committee's decision (see p. 139) for the Society to hold its annual meetings separately from the AAPG and SEPM will make certain changes desirable in the Society's By-Laws. The Committee on Constitution and By-Laws has accordingly proposed the following amendments to the Council for consideration at its April meeting in St. Louis:

Article VII:

Section 3: For "October" substitute "April"

Sections 4 and 5: for "December" substitute "June"

Section 7: For "January" substitute "July"

Section 8: For "February" substitute "August"

Article X:

Section 1-E: For "Standing Committee on Program and Arrangements" substitute "one or more General Committees for the Annual Meetings"

Section 7: Replace the entire section by the following: "The General Committee for the Annual Meeting to be held in a given year shall consist of a General Chairman and such additional persons as he may deem desirable. The General Chairman shall be appointed by the President with the concurrence of the Vice-President one or more years in advance of the Annual Meeting for which he is responsible and shall serve until the completion of all business related to the Annual Meeting. The other members of the General Committee, the Chairmen and members of any Committees to handle specific phases of the Annual Meeting shall be appointed by the General Chairman. The General Committee for the Annual Meeting shall have the duty of arranging and holding the Annual Meeting at a time and place designated by the Executive Committee."

Section 15: For "July" substitute "January"

In clarification of these amendments, Dr. W. M. Rust, Jr., Chairman of the Committee, has sent the following statement to Mr. Roy L. Lay, Society President:

"I believe that these modifications are self-explanatory except for Section 7, Article X. This is based on a recognition that holding a separate meeting will involve direct responsibility for many details which in the past have been handled at least in part by the AAPG. For this reason, the General Chairman for the Annual Meeting will need to be appointed probably two years in advance of the meeting and will require a substantial amount of local assistance.

"The constitution provides that officers shall assume the duties of the respective offices immediately after the close of the Annual Meeting following their election. The action of the Executive Committee provides that the SEG will meet jointly with the AAPG and SEPM in the spring of 1954 and in the spring of 1955, and that the SEG will holds its first separate Annual Meeting in the fall of 1955, and that subsequent Annual Meetings will be held in the fall. On this basis, if the meeting in the spring of 1955 is designated as a Joint Meeting, and the meeting in the fall of 1955 is designated as the Annual Meeting, the officers who assume their duties at the close of the Annual Meeting in the spring of 1954 will serve until the close of the Annual Meeting in the fall of 1955—some 18 months instead of the usual 11 to 13 months. The election of 1955 will be held in June, 1955, rather than December, 1954. There will, of course, be no election in June of 1954. I believe that this procedure will satisfy the terms of the Constitution and By-Laws and will provide an orderly transitional procedure.

The resolution by which the Council adopts these amendments should contain a statement to the effect that under the terms of these amendments the officers who take office in April, 1954, will hold office until the close of the Annual Meeting in the fall of 1955.

Respectfully submitted,
W. M. RUST, JR., *Chairman*
Constitution and By-Laws Committee

ANNOUNCEMENT OF PROGRAM
24TH ANNUAL MEETING
SOCIETY OF EXPLORATION GEOPHYSICISTS
ST. LOUIS, MISSOURI

SUNDAY, APRIL 11

All Day—Registration—Jefferson Hotel

MONDAY, APRIL 12

All Day—Exhibitors' Day
All Day—Registration—Kiel Auditorium
8:00 A.M.—Executive Committee
1:00 P.M.—Field Trip
3:00 P.M.—Annual Council Meeting
12:30 P.M.—Symposium on Safety

1. Extra Dividends from Safety, T. O. Hall
2. The Dollar Value of Safety to the Geophysical Operator, F. F. Reynolds
3. Safety Pays Small Business, Too, A. M. Baltzer
4. The Accident Profile, Fred Claiborne
5. Geophysical Accident Facts, B. W. Sorge
6. Safe Handling and Use of Explosives in Seismic Operations, Lindley Lathum

TUESDAY MORNING, APRIL 13

9:00 A.M.—Joint Session Opening Exercises, Presidential Addresses, Honors and Awards

TUESDAY AFTERNOON, APRIL 13

2:00 P.M.—Technical Session

1. Mamou Field—A Case History, D. Ray Dobyns and W. B. Roper
2. Improvement of Seismic Data by Computing Procedures, Roland F. Beers and Clifford F. Casey
3. Correlation Analysis of Seismic Exploration Data, Hal J. Jones and John A. Morrison
4. Introduction of New Officers and Business Meeting, Roy L. Lay
5. Energy Distribution in Explosion-Generated Seismic Pulses, B. F. Howell, Jr., and D. Budenstein
6. Recording of Seismic Waves in Bore Holes, E. T. Howes
7. Geophysical Activity in 1953, Sigmund Hammer
8. Using Geophysics in Vatican City, Daniel Linehan

WEDNESDAY MORNING, APRIL 14

9:00 A.M.—Joint Technical Session

1. Significant Exploration Developments of 1953, Philip C. Ingalls
2. Introduction to the Oil and Gas Geology of the Great Plains Region, Theo. A. Link
3. Geologic Framework of the Gulf Coastal Plain of Texas, J. W. Waters, P. W. McFarland, and J. W. Lea
4. The Present State of Geothermal Investigations, Francis Birch
5. A Seismic Reflection Quality Map of North America, Paul L. Lyons
6. Thickness Maps as a Criteria for Regional Structural Movements, Wallace Lee
7. Oil and Gas Production from Non-Reef Carbonate Reservoirs, Frank B. Conselman

WEDNESDAY AFTERNOON, APRIL 14

2:00 P.M.—Technical Session

1. Some Problems of Standardization in Recording Seismic Data on Magnetic Tape, Roland F. Beers and Clifford F. Casey
2. Recent Results of the Model Seismology Program at the Lamont Geological Observatory, Jack E. Oliver, Frank Press, and Maurice Ewing

3. The Duck Lake Field—St. Martin Parish, Louisiana, Edd R. Turner, Jr.
4. Reflection Quality, A Fourth Dimension, Ben F. Rummerfield
5. A Magnetic Compounder for Directional Discrimination of Seismic Waves, C. C. Lash, T. H. Gilmartin, and J. D. Eisler
6. Field Experience with Magnetic Recording of Seismic Data, R. A. Peterson
7. The Least Squares Approach to the Residual Analysis of Gravity Data, Thomas J. Bevan
8. Two-Dimensional Smoothing, with Special Reference to Gravity, Thomas A. Elkins

THURSDAY MORNING, APRIL 15

8:30 A.M.—Technical Session on Mining Geophysics

1. Resistivity Surveys over Slump Structures, Tri-State Lead-Zinc Mining District, Cherokee County, Kansas, Kenneth L. Cook
2. The Application of Electric Logging to a Minerals Exploration Program, G. V. Keller
3. Resistivity Methods Applied to Some Ground Water Studies, H. Cecil Spicer
4. The Ore Contact Method of Electrical Exploration, J. Ewart Blanchard
5. The Use of Geophysical Methods for Base Metals Explorations in Northern New Brunswick, Harold O. Seigel
6. Geophysical Case History of the Anacon-Leadridge Base Metal Orebody in New Brunswick, Canada, Stanley H. Ward
7. A Case History of the Geophysical Discovery of the Pima Mine, Pima County, Arizona, Walter E. Heinrichs, Jr. and Robert E. Thurmond
8. Investigation of Mineral Deposits in Australia by Geophysical Methods, R. F. Thyer
9. Geophysical Prospecting in the Union of South Africa, J. F. Enslin
10. A New Electromagnetic Field Technique, J. F. Enslin
11. Instrumentation and Apparatus for a New Electromagnetic Field Technique as Applied in South Africa, G. ff. Bellairs
12. Geophysical Prospecting for Iron Ore in the Lake Superior Region, Lloyal O. Bacon
13. Gravity Meter Surveys at Steep Rock Iron Mines, G. R. Johnson
14. Geophysical Investigations in the Mojave Desert Area of California, Don R. Mabey
15. Electromagnetic Surface Waves Over Geological Conductors, James R. Wait
16. Iron and Titanium Oxide Minerals of Adirondack Rocks and Their Magnetic Properties, J. R. Balsley and A. F. Buddington

THURSDAY AFTERNOON, APRIL 15

2:00 P.M.—Technical Session

1. The Ionium Method of Age Determination—Recent Developments, Herbert L. Volchok and J. Laurence Kulp
2. Subsurface Formation Density Logging, G. R. Newton, J. E. Skinner, and D. Silverman
3. Public Relations in Canadian Mining Geophysics, Canadian Exploration Geophysicists
4. Geophysical and Geological Investigations in the Gulf of Mexico, Maurice Ewing, J. L. Worzel, D. B. Ericson, and Bruce C. Heezen
5. Cotton Valley Strand-Line Fields in North Louisiana, John H. Crump
6. Helicopters—A Versatile Exploration Tool, Frank W. Lee
7. Transmission Characteristics of Near Surface Layers, Barton County, Kansas, Robert B. Fisher
8. Multiple Reflection Evidence in Northwestern Kansas, Adrian A. Becker and John M. Crawford
9. Radioactivity Measurements in the Los Angeles Basin, H. Wayne Hoylman (By title only)

6:00 P.M.—Cocktail Party

7:30 P.M.—Dinner Dance

FRIDAY, APRIL 16

All Day—Field Trip

Numerous alumni luncheons are being scheduled and a mining geophysics breakfast is planned for 7:00 A.M., Thursday, April 15.

PROFESSIONAL DIRECTORY

CALIFORNIA

C. HEWITT DIX
Geophysical Consultant
1201 East California Street
PASADENA 4, CALIFORNIA
SYcamore 6-7121 RYan 17171

H. WAYNE HOYLMAN
Consultant
Petroleum and Mining Exploration
Hoylman-Morris 816 W. 5th St.
Mutual 6428 Los Angeles 17, Calif.

J. J. JAKOSKY
International Geophysics, Inc.
Consulting Geophysicists
1063 Gayley Ave.
LOS ANGELES 24, CALIF.

HENRY SALVATORI
Western Geophysical Company of America
1116 Pacific Mutual Bldg.
523 W. 6th Street
LOS ANGELES 14, CALIFORNIA

JOSHUA L. SOSKE
Geologist and Geophysicist
SCHOOL OF MINERAL SCIENCES
Stanford University
STANFORD, CALIFORNIA

ELLIOTT SWEET
Gravity Meter Surveys
Gravity and Seismic Interpretation
SWEET GEOPHYSICAL CO.
21544 Rambla Vista Drive
MALIBU, CALIFORNIA

COLORADO

E. F. BLAKE
Southern Geophysical Co.
504 Denver Theater Building
DENVER, COLORADO

C. A. HEILAND
130 East Fifth Avenue
DENVER, COLORADO

KANSAS

Haakon Muus Evjen
"HANK"
Consultant in Geophysics
ELECTRIC SURVEYS
Interpretation of all Geophysical Problems
1219 Riverside Ave.
Wichita 3, Kansas Telephone 7-4854

LOUISIANA

CARL L. BRYAN
Consulting Geophysicist-Geologist
804 Texas Eastern Bldg. Telephone
SHREVEPORT, LA. 5-1924

MISSISSIPPI

EWIN D. GABY
Delta Exploration Company
Jackson Mississippi

MISSOURI

LEROY SCHARON

Mining and Engineering Geophysics

567 Brookhaven Court
Kirkwood 22 Phone
St. Louis, Missouri KIrkwood 1578-W

OKLAHOMA

W. B. AGOCS

Geophysical Consultant

Geological-Geophysical Coordination
Seismograph, Gravitymeter, Magnetometer

544 S. Zurich Tulsa 12, Okla.

THOMAS J. BEVAN

Geophysicist

914 American Airlines Bldg. Phone 2-7508
TULSA 3, OKLAHOMA

NEAL CLAYTON

Seismic Surveys and Re-interpretation

LIBERTY EXPLORATION COMPANY

1307 E. 38th Phone 7-5771
TULSA, OKLAHOMA

OPIE DIMMICK

Century Geophysical Corp.
Tulsa, Oklahoma Phone 5-7111

ROBERT E. FEARON

Registered Professional Engineer-Geophysicist

Nuclear and Electrical Instrumentation
Well Logging Developments

Safety Engineering—Radiochemistry—Isotopes
2207 E. 6th St. Tulsa 4, Okla.

CRAIG FERRIS

Geophysicist

E. V. McCollum & Co. GeoSeis, Inc.

515 Thompson Bldg.
TULSA 3, OKLA.

OKLAHOMA

MIDWESTERN GEOPHYSICAL LABORATORY

E. J. Handley 3401 South Harvard
Executive Vice President Telephone 7-7521

V. L. JONES

Consulting Geophysicist

1412 South Norfolk Tulsa 14, Oklahoma

MANHART, MILLISON & BEEBE

Petroleum Exploration Consultants
Domestic and Foreign

T. A. Manhart C. H. Jameson, Jr.
Clark Millison John J. Rupnik
B. W. Beebe Thomas E. Matson
Carl W. Blakey A. L. Ballou, Jr.

Jenkins Building
TULSA, OKLAHOMA

TOM D. MAYES

Mayes-Bevan Co.

Gravity Meter Surveys
and Interpretations

305 Kennedy Building
TULSA, OKLAHOMA

E. V. McCOLLUM

Geophysicist

E. V. McCollum & Co.

515 Thompson Building

TULSA, OKLAHOMA

GLENN M. McGUCKIN

Seismograph Consultant

1304 Ann Arbor Phone 853
NORMAN, OKLAHOMA

Data Reviews Fault Areas
Reef Analyses Supervision
McGuckin Automatic Seismograph Section
Plotter Sales
(19 years experience, including: Organizer and former joint-owner Reliable Geophysical Co.)

BEN F. RUMMERFIELD

Geologist and Geophysicist

CENTURY GEOPHYSICAL CORPORATION

1333 N. Utica 223 Examiner Bldg.
Tulsa, Oklahoma Calgary, Alberta

OKLAHOMA

JOHN J. RUPNIK

Geophysicist & Geologist

MANHART, MILLISON & BEEBE

503 Jenkins Bldg. Tulsa 3, Okla.

HUGH C. SCHAEFFER

Geologist & Geophysicist

Schaeffer Geophysical Co.

Federal National Bank Bldg.
SHAWNEE, OKLA.

TEXAS

JOSEPH L. ADLER

Geologist and Geophysicist

Foreign Geophysical Surveys

Independent Exploration Company

P.O. Box 13237 Houston 19, Texas

THOMAS L. ALLEN

Portable Seismograph, Inc.

721 Frost National Bank Building

San Antonio 5, Texas

JOHN F. ANDERSON

ANDERSON & COOKE
Oil Exploration Consultants
Geological Consulting
Seismic Surveys & Interpretations

500 San Jacinto Bldg. Houston 2, Texas

WALTER D. BAIRD

Consulting Geophysicist

NEIL P. ANDERSON BUILDING

PHONE FORTUNE 8400 FORT WORTH 2, TEXAS

KEITH R. BEEMAN

Electronic Consultant

Seismograph and Allied Equipment

P.O. Box 13058
Houston, Texas

TEXAS

ROLAND F. BEERS

Beers and Heroy

P.O. Box 1015
TROY, NEW YORK

3712 Haggar Drive
P.O. Box 7166
DALLAS, TEXAS

JOHN L. BIBLE

TIDELANDS EXPLORATION CO.

Seismic and Gravity Surveys on Land and Sea
Geophysical Interpretations

2626 Westheimer
HOUSTON, TEXAS

HART BROWN

Brown Geophysical Company

Gravity-Meter-Surveys

Interpretations

5300 Brownway Rd. Houston 19, Texas

JOHN W. BYERS

States Exploration Company

Seismic, Gravity and Magnetic Surveys

709 M. & M. Building P. O. Box 845
HOUSTON, TEXAS SHERMAN, TEXAS

R. A. CRAIN

Texas Seismograph Company

Panhandle Building

WICHITA FALLS, TEXAS

PAUL D. CRAWFORD

Askania Magnetometer
Surveys

1421 Milam Bldg. San Antonio, Texas

R. H. DANA

Southern Geophysical Company

6640 Camp Bowie

FORT WORTH, TEXAS

TEXAS

J. F. FREEL

RESEARCH EXPLORATIONS, INC.

2136 Welch
Houston 19, Texas

E. Joe Shimek Hart Brown

GEOPHYSICAL ASSOCIATES

P.O. Box 6005 Houston 6, Texas

Seismic

JOHN A. GILLIN

National Geophysical Company

8800 Lemmon Avenue

Dallas 9, Texas

IRVING M. GRIFFIN, JR.

Consultant in
Seismic Review and Interpretation
and
Field Crew Supervision

FAirfax 9111 1331 Esperson Bldg.
JAckson 4558 Houston 2, Texas

T. I. HARKINS

Independent Exploration Company

1973 West Gray
P.O. Box 13237
Houston 19, Texas

J. G. HARRELL

Mid-Continent Geophysical Co.

Contract Seismograph Crews
Seismic-Reinterpretations

2509 West Berry Fort Worth, Texas

TEXAS

SIDON HARRIS

Southern Geophysical Company

6640 Camp Bowie Blvd. Fort Worth, Texas

J. O. HOARD

HOARD EXPLORATION COMPANY

Esperson Building Houston, Texas

W. B. HOGG

Geophysical Consultant

820 Fidelity Union Life Bldg.

DALLAS 1, TEXAS

LEO HORVITZ

Geochemical Prospecting

Horvitz Research Laboratories
3217 Milam Street
HOUSTON, TEXAS

JOHN S. IVY

Niels Esperson Building

HOUSTON, TEXAS

J. C. KARCHER

Geophysicist

Gulf States Bldg.
DALLAS, TEXAS

MARTIN C. KELSEY

Rayflex Exploration Company

6923 Snider Plaza Dallas 5, Texas

TEXAS

H. KLAUS
Geologist and Geophysicist
Klaus Exploration Company
Gravimetric and Magnetic Surveys
and Interpretations
P.O. Box 1617 Lubbock, Texas

PAUL H. LEDYARD
Mid-Continent Geophysical Co.
Contract Seismograph Crews
Seismic-Reinterpretations
2509 West Berry Fort Worth, Texas

HAYDON W. McDONNOLD
Geologist & Geophysicist
Keystone Exploration Company
2813 Westheimer Road
HOUSTON, TEXAS

A. E. "SANDY" McKAY
Geologist and Geophysicist
Continental Geophysical Co.
FORT WORTH, TEXAS
602 Continental Life Bldg. Phone FAnnin 9231

GEORGE D. MITCHELL, JR.
Geologist and Geophysicist
1222 Mercantile Securities Bldg. Dallas, Texas

CHAS. GILL MORGAN
805 Mercantile Securities Bldg.
DALLAS, TEXAS
RAndolph 7963

P. E. NARVARTE
Consulting Geophysicist
Seismic Interpretations
Current Supervision and Review
Frost National Bank Building
San Antonio, Texas

TEXAS

L. L. NETTLETON
Gravity Meter Exploration Co.
Interpretation of Gravity Surveys
Interpretation of Aeromagnetic Surveys
340 M. Esperson Bldg.
HOUSTON 2, TEXAS

W. W. NEWTON
Geophysicist
823 Corrigan Tower
DALLAS, TEXAS

C. W. PAYNE
Payne & Warren
Geophysical Consultants
Fort Worth TEXAS

H. B. PEACOCK
Consulting Geophysicist
9746 Audubon Place
DALLAS 20, TEXAS

J. D. PERRYMAN
The Geotechnical Corp.
P.O. Box 7166
Dallas 9, Texas Phone DIxon 3946

J. C. POLLARD
GEOPHYSICAL ENGINEERING
•
SEISMIC . . . GRAVITY . . . MAGNETIC SURVEYS
•
2500 Bolsover Rd., P.O Box 6557, Houston 5, Tex.

ROBERT H. RAY
GEOPHYSICAL ENGINEERING
•
SEISMIC . . . GRAVITY . . . MAGNETIC SURVEYS
•
2500 Bolsover Rd., P.O. Box 6557, Houston 5, Tex.

TEXAS

SAM D. ROGERS
Rogers Geophysical Company
Rogers Explorations, Sociedad Anonima
3616 West Alabama Houston 6, Texas

E. E. ROSAIRE
Petroleum Prospecting
SUBTERREX
6645 Northaven Road
DALLAS 30, TEXAS

P. T. RUMSEY
Portable Seismograph, Inc.
District Office
205-07 West Bldg. Ph: 4-4932
Midland, Texas

RAYMOND L. SARGENT
Magnetometer Surveys
Interpretations
M & M Bldg.
HOUSTON 2, TEXAS

SIDNEY SCHAFER AND COMPANY
Geophysicists and Geologists
EXPLORATION CONSULTANTS
Domestic and Foreign
Sidney Schafer
J. Calvin Weyand 2200 Welch Avenue
John W. White Houston 19, Texas

HUBERT L. SCHIFLETT
States Exploration Company
Seismic, Gravity and Magnetic Surveys
709 M. & M. Building 214 M & P Bldg.
HOUSTON, TEXAS SHERMAN, TEXAS

THOMAS R. SHUGART
Geologist and Geophysicist
TEXANA EXPLORATION COMPANY
1228 Mercantile Securities Bldg. Dallas, Texas

TEXAS

H. B. SMYRL
Portable Seismograph, Inc.
721 Frost National Bank Bldg.
San Antonio 5, Texas

NELSON C. STEENLAND
Gravity Meter Exploration Company
Geophysicist
340 Mellie Esperson Building Houston, Texas

R. C. SWEET
Geophysicist
NORTH AMERICAN GEOPHYSICAL COMPANY
2627 Westheimer Road, Houston, Texas

R. MAURICE TRIPP
Oil and Mineral Exploration Research
3525 Beverly Drive Dallas, Texas

KIRBY J. WARREN
Payne & Warren
Geophysical Consultants
Fort Worth Texas

S. PRESTON WEATHERBY
Geophysicist
DONNALLY GEOPHYSICAL COMPANY
1315 Cadiz Street, Dallas, Texas

E. DARRELL WILLIAMS
Geophysicist
3114 Prescott Street
HOUSTON 25, TEXAS

TEXAS

JOHN H. WILSON

Exploration Consultant

1201 Sinclair Bldg.

FORT WORTH, TEXAS

ALEXANDER WOLF

Consultant in Geophysics

Design and construction of instruments
Development of geophysical procedures
Interpretation of geophysical data

2518 Huldy St. Houston 19, Texas

CHARLES C. ZIMMERMAN

Geologist & Geophysicist

Keystone Exploration Company
2813 Westheimer Road
HOUSTON, TEXAS

WYOMING

Exploration Geology Seismic Reviews
Evaluations Seismic Supervision

JOHN F. PARTRIDGE, JR.

Consulting Geologist—Geophysicist

P. O. Box 258 Room 211 O-S Building
Phones 2-6485 and 2-3328 CASPER, WYOMING

CANADA

JOHN O. GALLOWAY

Petroleum Consultant

627 8th Ave., W. Calgary, Alberta

THEODORE KOULOMZINE

Geologist & Geophysicist
Koulomzine, Geoffroy & Co.
P. O. Box 870
VAL D'OR Qué. Canada.

LUNDBERG EXPLORATIONS LIMITED

Consulting Geologists and Geophysicists

Specialty—Airborne, Radiation, Electrical & Magnetic Surveys
80 Richmond St. W.
Toronto, Canada

CANADA

OSCAR WEISS · *Geophysicist*

Mining and Petroleum Exploration
Weiss Geophysical Corporation
P.O. Box 118, Wilmington 99, Delaware
902-904, Mutual Buildings
Commissioner Street
Johannesburg, South Africa
Weiss Geophysical Corporation of Canada
Greyhound Building
Calgary, Alberta, Canada

GEOPHYSICAL SOCIETIES

ARK-LA-TEX GEOPHYSICAL SOCIETY

SHREVEPORT, LOUISIANA

President: R. B. BAUM, Seismograph Service Corp., Shelby Building, Shreveport.

Vice-President: L. H. WELLS, Arkansas Fuel Oil Corp., Box 1734, Shreveport.

Secretary-Treasurer: E. A. MALONE, Gulf Refining Co., Box 1731, Shreveport.

CANADIAN SOCIETY OF EXPLORATION GEOPHYSICISTS

CALGARY, ALBERTA, CANADA

President: W. P. OGILVIE, Accurate Geophysical Ltd., 1023 11th Ave. W., Calgary.

Vice-President: W. BAILLIE, Frontier Geophysical Ltd., 1504-A 14th St. W., Calgary.

Secretary-Treasurer: H. COX, Western Geophysical Co. of Canada Ltd., 828 4th Ave. E., Calgary.

CASPER GEOPHYSICAL SOCIETY

CASPER, WYOMING

President: WENDALL H. HAWKES, Stanolind Oil & Gas Co., Box 40, Casper.

Vice-President: T. L. MCCORKLE

Secretary-Treasurer: J. E. BROOKSHIRE

DALLAS GEOPHYSICAL SOCIETY

DALLAS, TEXAS

President: C. G. DAHM, Hunt Oil Co., 3625 Bryn Mawr Dr., Dallas 25.

1st Vice-President: J. D. PERRYMAN, Geotechnical Service Corp., Box 7166, Dallas 9.

2nd Vice-President: J. A. LESTER, Magnolia Petroleum Co., 3521 Bryn Mawr, Dallas 5.

Secretary-Treasurer: E. J. Stulken, Geophysical Service Inc., 5900 Lemmon Ave., Dallas 19.

DENVER, GEOPHYSICAL SOCIETY

DENVER, COLORADO

President: MARVIN ROMBERG, The Carter Oil Co., Box 120, Denver.

Vice-President: C. K. SHEPHERD, Continental Oil Co., Continental Oil Building, Denver.

Secretary-Treasurer: C. L. BARKER

FORT WORTH GEOPHYSICAL SOCIETY

FORT WORTH, TEXAS

President: L. O. SEAMAN, Sinclair Oil & Gas Co., 901 Fair Building, Fort Worth.

Vice-President: W. D. BAIRD, Baird Geophysical Co., 917 Neil P. Anderson Bldg., Fort Worth.

Secretary-Treasurer: MISS ROBBIE G. RUTHERFORD, Stanolind Oil & Gas Co., Box 1410, Fort Worth.

GEOPHYSICAL SOCIETY OF OKLAHOMA CITY

OKLAHOMA CITY, OKLAHOMA

President: GEORGE V. DUNN, Stanolind Oil & Gas Co., Box 1654, Oklahoma City.

1st Vice-President: FRANK ROBERTS, The Carter Oil Co., 1116 Liberty Bank Bldg., Oklahoma City.

2nd Vice-President: LYNN D. ERVIN, Stanolind Oil & Gas Co., Box 1654, Oklahoma City.

Secretary: EUGENE STONES, The Superior Oil Co., 2200 Liberty Bank Bldg., Oklahoma City.

Treasurer: MARVIN HEWITT, Stanolind Oil & Gas Co., Box 1654, Oklahoma City.

GEOPHYSICAL SOCIETY OF TULSA

TULSA, OKLAHOMA

President: NORMAN RICKER, The Carter Oil Co., Box 801, Tulsa.

1st Vice-President: JOHN M. CRAWFORD, Continental Oil Co., Ponca City, Oklahoma.

2nd Vice-President: R. W. MOSSMAN, Seismograph Service Corp., Box 1590, Tulsa.

Secretary: TOM F. SOUTHGATE, Amerada Petroleum Corp., Box 2040, Tulsa.

Treasurer: DAVID R. WEICHERT, Century Geophysical Corp., Box 6216, Tulsa.

PACIFIC COAST SECTION SOCIETY OF EXPLORATION GEOPHYSICISTS

President: ROBERT B. GALESKI, Honolulu Oil Corp., Box 3116, Bakersfield, California.

Vice-President Northern District: W. D. CORTRIGHT, Tide Water Associated Oil Co., 308 Hopkins Bldg., Bakersfield, California.

Vice-President Southern District: CARL SAVIT, Western Geophysical Co., 523 West Sixth St., Los Angeles 14, California.

Secretary-Treasurer: ROBERT J. WELLS, Richfield Oil Corp., Box 147, Bakersfield, California.

SOCIETY OF EXPLORATION GEOPHYSICISTS HOUSTON, TEXAS, SECTION

President: J. E. MCGEE, Gulf Oil Corp., Box 2100, Houston.

1st Vice-President: W. HARLAN TAYLOR, Taylor Exploration Co., Inc., 2118 Welch Ave., Houston.

2nd Vice-President: RAY H. WRIGHT, Geophysical Service, Inc., 839 Esperson Bldg., Houston.

Secretary: GEORGE P. MONTGOMERY, JR., Humble Oil & Refining Co., Box 2180, Houston.

Treasurer: JAMES M. WILSON, Houston Oil Co., Box 2412, Houston.

PERMIAN BASIN GEOPHYSICAL SOCIETY

BOX 1018

MIDLAND, TEXAS

President: C. N. PAGE, Continental Geophysical Co., 500 Holmsley, Midland.
1st Vice-President: W. A. REEVES, Midland Geophysical Co., 233 Capitol Bldg., Midland.
2nd Vice-President: CHARLTON KERR, Continental Oil Co., Box 431, Midland.
Secretary: VICTOR BYCHOK, The Atlantic Refining Co., Box 871, Midland.
Treasurer: LINDLEY LATHAM, E. I. DuPont de Nemours & Co., 2207 Bedford, Midland.

DAKOTA GEOPHYSICAL SOCIETY

BISMARCK, NORTH DAKOTA

President: CARROLL M. ENGLAND, Union Oil Co. of Calif., Box 334, Bismarck.

1st Vice-President: RALPH H. HOWE, The California Co., Bismarck.

2nd Vice-President: WILLIAM HARLEY, Hercules Powder Co., Bismarck.

Secretary-Treasurer: E. B. COLE, Cities Service Oil Co., Bismarck.

COLORADO SCHOOL OF MINES

DEPARTMENT OF GEOPHYSICISTS

SOCIETY OF STUDENT GEOPHYSICISTS

GOLDEN, COLORADO

President: JOHN WOOD
Vice-President: DAN RICHARDSON
Secretary-Treasurer: CHARLES MARQUARDT
Faculty Sponsor: PROF. JOHN C. HOLLISTER

GEOPHYSICAL SOCIETY OF SAINT LOUIS UNIVERSITY

INSTITUTE OF TECHNOLOGY

3621 OLIVE STREET

ST. LOUIS 8, MISSOURI

President: JOHN J. MCCORMICK
Vice-President: CHARLES M. DALY
Secretary: MICHAEL C. FORREST
Treasurer: RONALD E. HAUG
Faculty Sponsor: REV. JAMES B. MACELWANE, S.J.

UNIVERSITY OF TORONTO GEOPHYSICAL SOCIETY

DEPARTMENT OF GEOPHYSICS

49 ST. GEORGE STREET

TORONTO 5, ONTARIO, CANADA

President: H. A. SHILLIBEER
Vice-President: E. A. W. JONES
Secretary-Treasurer: R. M. FARQUHAR
Faculty Sponsor: PROF. J. TUZO WILSON

Exploring in Western Canada?

Looking for oil in Canada's great northwest? Our mapping crews are now carrying forward airborne magnetometer surveys in the Prairie Provinces and British Columbia. These surveys are yielding important facts about regional trends, basement structures, and other geologic features, to aid the ground search.

We have more aerial exploration experience than anybody else . . . over 400,000 miles of airborne magnetometer surveys since 1950. Can we aid your exploration program now?

For technical information, call on our experienced mapping and engineering personnel.

CANADIAN
AERO
SERVICE, LTD.
348 QUEEN STREET, OTTAWA, ONTARIO

For Better Seismograph Service

TEXAS SEISMOGRAPH CO.

PANHANDLE BLDG. WICHITA FALLS, TEXAS

JOURNAL OF APPLIED PHYSICS

This is a monthly journal designed particularly for those applying physics in industry and in other sciences. It publishes reviews of recent progress in applied physics, original research papers, news, and advertisements.

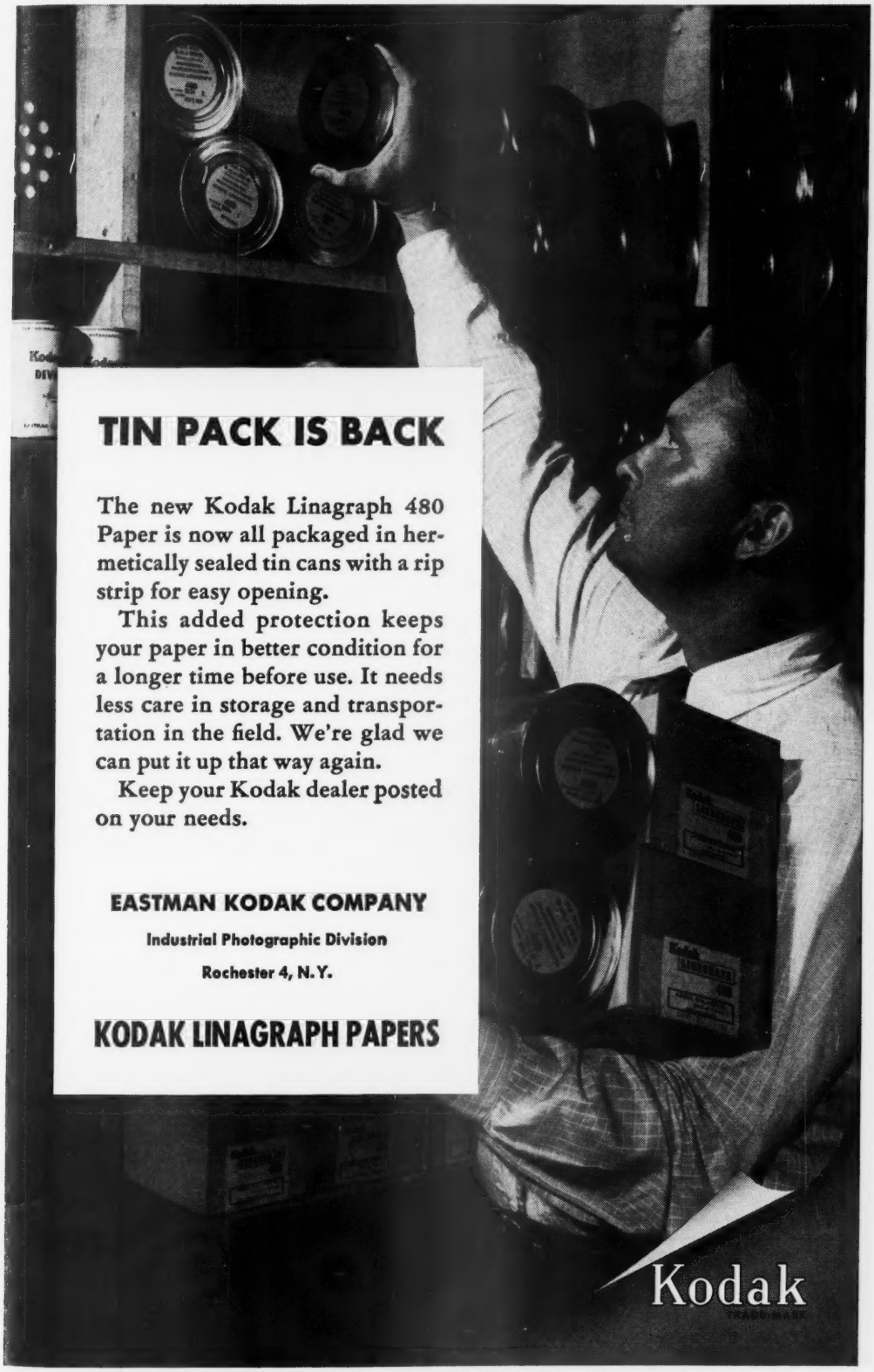
Subscription Price	U.S. Poss. and Canada	Foreign
To members of American Institute of Physics	$10.00	$11.00
To all others	12.00	13.00

Single copies—$1.25

Address

AMERICAN INSTITUTE OF PHYSICS

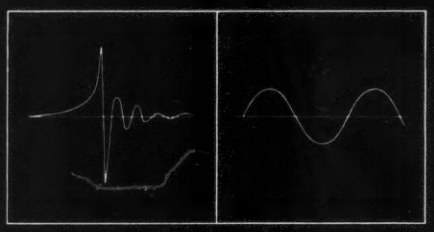
57 East 55 Street New York 22, N.Y.

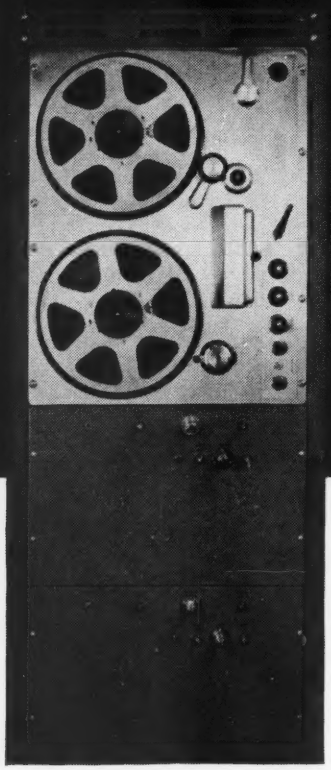

TIN PACK IS BACK
The new Kodak Linagraph 480 Paper is now all packaged in hermetically sealed tin cans with a rip strip for easy opening.
This added protection keeps your paper in better condition for a longer time before use. It needs less care in storage and transportation in the field. We're glad we can put it up that way again.
Keep your Kodak dealer posted on your needs.
EASTMAN KODAK COMPANY
Industrial Photographic Division
Rochester 4, N.Y.
KODAK LINAGRAPH PAPERS
Kodak

ANNOUNCING

THE AMPEX 306 DATA RECORDER

A new machine that solves more data recording problems than any new instrument since the oscillograph





Like the direct magnetic tape recorder, the AMPEX 306 presents data in "live" electrical form that can be scanned, speeded up, slowed down, automatically reduced or converted to any electrical, visual or physical form.

But unlike any previous magnetic tape recorder, the AMPEX 306 has a frequency response down to D.C. and has high transient accuracy that is essentially independent of irregularities in the tape it uses. The AMPEX 306 has a range, accuracy and versatility never before approached by any magnetic tape recording device.

APPLICATIONS

- Recording of explosions, shock waves, geophysical data and other phenomena of a highly transient nature.
- Mechanical, physical or electrical phenomena falling in the frequency range 5000 cycles down to zero (D.C.).
- Data whose complexity and quantity makes automatic reduction, scanning or comparison desirable.
- Non-repeatable test situations requiring high reliability and comprehensiveness of data.

AMPEX 306 Magnetic Tape Recorder

For further information, write to Dept. 1-1039B

AMPEX

MAGNETIC RECORDERS

AMPEX ELECTRIC CORPORATION
934 CHARTER STREET • REDWOOD CITY, CALIF.

ANNOUNCEMENT

Midwestern Geophysical Laboratory is proud to announce that an arrangement has been made whereby the Ampex Corporation drum-type magnetic tape recording and playback geophysical unit will be integrated with Midwestern's new seismograph unit, which has been specially designed for magnetic recording operations. The integrated magnetic recording seismic units, both truck-mounted and portable, will be exclusively manufactured for sale by Midwestern Geophysical Laboratory. The individual Ampex magnetic recording units will continue to be sold, as before, by the Ampex Sales Department and their distributors. Midwestern Geophysical Laboratory is pleased to further announce the appointment of Southwestern Engineering and Equipment Company, 3906 Lemmon Avenue, Dallas, Texas, as an authorized sales agency for the Ampex-Midwestern integrated magnetic recording seismic units. Southwestern Engineering and Equipment Company will continue their representation of the Ampex Corporation, as before, and will therefore sell the individual Ampex magnetic recording units as well as the Ampex-Midwestern integrated seismic units.

The complete truck-mounted integrated unit will be available for delivery on or about April 1, 1954. The integrated unit is so designed that the broad-band records can be recorded on magnetic tape during routine field operations and the broad-band record can then be played back through the seismic amplifiers. The band-pass filters in the seismic amplifiers are so versatile that the optimum filter setting can be obtained utilizing the playback procedure. By means of the mixing panel in the seismic unit the operator can also utilize advantages of mixing when playing back the broad-band record. The desired degree of mixing can be obtained prior to filtering, thus improving the signal-to-noise ratio and permitting the use of a wider band-pass filter at the optimum position.

Service for the Ampex-Midwestern integrated seismic units will be performed by Midwestern, thereby providing the purchasers of the integrated units with a single source for service.

For additional information concerning the Ampex-Midwestern integrated seismic units, please write to:

MIDWESTERN GEOPHYSICAL LABORATORY
3401 South Harvard
Tulsa, Oklahoma

or . . . SOUTHWESTERN ENGINEERING and EQUIPMENT COMPANY
3906 Lemmon Avenue
Dallas, Texas

or . . . AMPEX CORPORATION
934 Charter
Redwood City, California

North American
Gravity Meters
for
STANDARD
EXPLORATION,
GEODETIC AND
MARINE WORK
•
Manufacturers of Geophysical
Equipment and Precision Apparatus
NORTH AMERICAN GEOPHYSICAL COMPANY
2627 Westheimer Rd., KEystone 7408
Houston 6, Texas

Someone **HAS TO DO THE**

GROUNDWORK

Experienced key personnel coupled with equipment of their own design and manufacture and carefully maintained, permit Republic's interpretative staff to make more reliable maps.

Republic now offers you a free map of the U.S. showing all major geological features. Write Republic Exploration, Box 2208, Tulsa, Oklahoma.

Rx

REPUBLIC EXPLORATION COMPANY

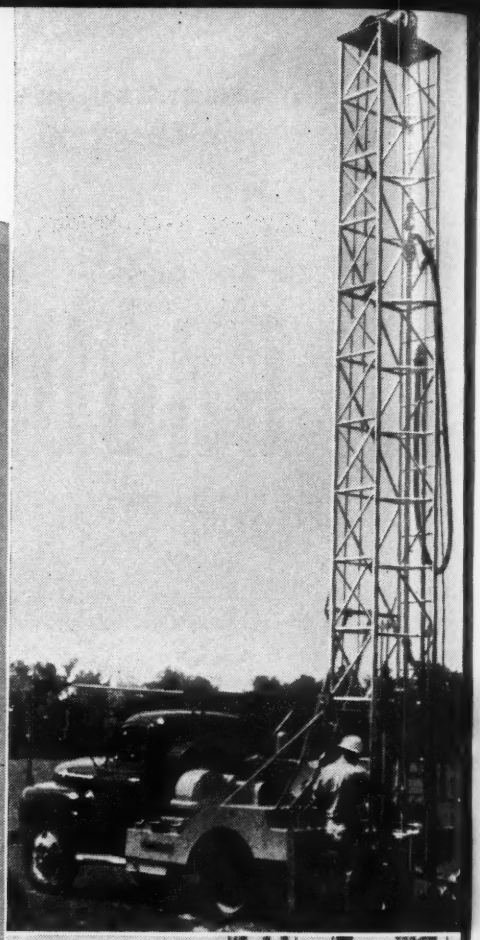
TULSA, OKLAHOMA — MIDLAND, TEXAS

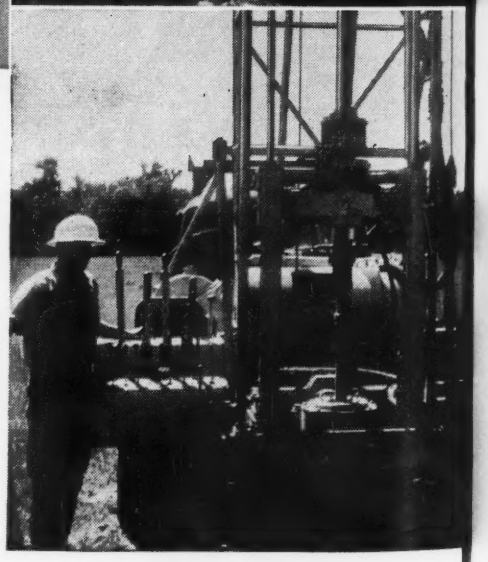
For SEISMOGRAPH, BLAST HOLE, WATERWELL and CORE DRILLING

The new "JOY 75"

PORTABLE DRILL RIG

With Cylinder-type Hydraulic Feed, or Chain Pull-down





Here's a self-contained, highly mobile, motorized drill rig that's built for fast, low-cost, continuous drilling under the toughest conditions.

The Joy "75" has a capacity of 750 ft. using 2⅜" pipe. The rotary table has a 6⅜" opening. The mast is raised and lowered hydraulically and is rigged to handle 10, 15, or 20 ft. lengths of pipe.

Heavy-duty construction is the rule throughout. Gearing and shafting are not adapted from standard truck parts but have been designed specifically for heavy-duty drilling. Other features include double-drum type draw-works, power make-up and break-out, and power take-off from truck engine.

Illustrated above is the Joy "75" with cylinder-type hydraulic feed. However, it is also available with chain pull-down (hydraulic motor driven). ● For full details on this remarkable new portable drill rig, ask for Bulletins RM-706 and RM-707. Address ***Joy Manufacturing Company, Oliver Building, Pittsburgh 22, Pa.*** In Canada: *Joy Manufacturing Company, (Canada) Limited, Galt, Ontario.*

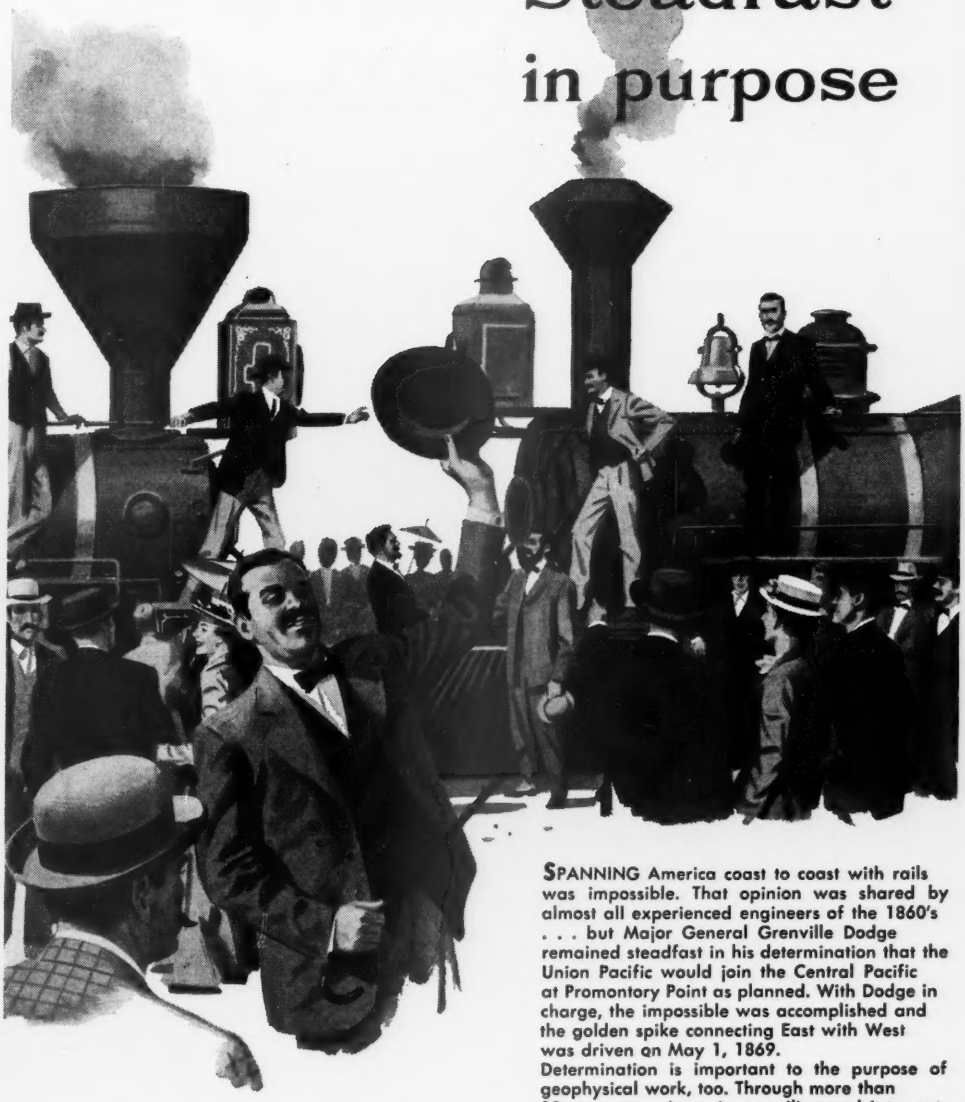
Consult a Joy Engineer

W&D O 4726

JOY

Leading Producers of Equipment fo Minerals Exploration and Productio

Steadfast in purpose



SPANNING America coast to coast with rails was impossible. That opinion was shared by almost all experienced engineers of the 1860's . . . but Major General Grenville Dodge remained steadfast in his determination that the Union Pacific would join the Central Pacific at Promontory Point as planned. With Dodge in charge, the impossible was accomplished and the golden spike connecting East with West was driven on May 1, 1869.

Determination is important to the purpose of geophysical work, too. Through more than 18 years experience in compiling and interpreting seismograph data, General's capable crews have helped many operators locate conditions favorable to find new oil reserves. Let us help you.

WHEN YOUR CONTRACT IS WITH GENERAL . . . THE PERCENTAGE IS IN YOUR FAVOR FOR SUCCESSFUL EXPLORATION.

General GEOPHYSICAL COMPANY
GULF BUILDING • HOUSTON, TEXAS

THE GEOPHYSICAL SOCIETY OF TULSA

announces the publication of

THE PROCEEDINGS OF THE GEOPHYSICAL SOCIETY OF TULSA

Vol. I (Joseph A. Sharpe Memorial)

This publication will be of interest to all geophysicists. In addition to reporting on the activities of the Tulsa society for the 1952-1953 period of meetings, the volume contains several original papers having a wealth of experimental data on the magnetic susceptibility and density of rocks.

Price $2.00

Address:

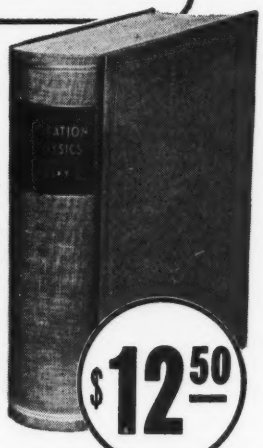
ROBERT J. WATSON, EDITOR
The Geophysical Society of Tulsa
Box 801
Tulsa, Oklahoma

An easily read, clearly illustrated text on

Modern Geophysical Techniques

EXPLORATION GEOPHYSICS

by J. J. Jakosky, Sc. D.



In 1200 pages and with 707 illustrations, the 1950 revised *Exploration Geophysics* covers the entire field of exploration by modern geophysical methods. It is concisely and clearly written by an internationally known geophysicist, in close collaboration with 39 other leading authorities.

Thirteen fact-packed chapters fully cover all contemporary methods; plus permit, trespass and insurance problems. A basic textbook for every geologist, geophysicist, engineer and physicist concerned with exploration, well logging and production. Adopted by many leading universities.

FREE EXAMINATION

Send your money order or check for $12.50 for a copy of Exploration Geophysics on 5-day approval. If you are not fully satisfied, merely return the book in its original condition and your money will be promptly refunded.

TRIJA PUBLISHING COMPANY, TRIJA BUILDING, LOS ANGELES 24, CALIFORNIA

WILLIAM M. BARRET, INC.
CONSULTING GEOPHYSICISTS
GIDDENS-LANE BUILDING
SHREVEPORT 4, LOUISIANA

LABORATORY
FAIRFIELD AVENUE

PROGRESS REPORT
Radio Exploration

During 1953 Radoil* crews have been at work for 3 major oil companies and 7 independents, with 3 major mining companies and 3 independents using Radore* crews. These 16 accounts, which have been served by our own crews and by those of our licensees, make 1953 the most active year in our 26-year history. Further expansion is expected with the early completion of our new geophysical plant and the availability in 1954 of additional field equipment.

*Trade-Mark and Service Mark
Registered U. S. Patent Office.

THE PIONEERS OF

Refraction Shooting • Reflection Shooting • Well Shooting • Marine Shootin

. . . also providing Gravity Meter Surveys for preliminary exploration

DOMESTIC
AND FOREIGN
EXPLORATION

McCOLLUM SINCE 1923
Exploration Company

1025 South Shepherd Drive, Houston 19, Texas • Phone: JUstin 5427
526 Eighth Avenue West, Calgary, Alberta, Canada • Phone: Main 3191

For Safe, Efficient

for

dependable . . .

experienced . . .

Exploration Drilling

Braithwaite & Caldwell

Enid, Oklahoma, U. S. A.

Al Braithwaite

Walter T. Caldwell

For Safe, Efficient, Economical Drilling

. . . *specify*

SPANG

CABLE TOOLS

"The Higher Standard"

Spang Cable Tools stand out as the top performers in their field for:

- Shot Hole Drilling
- Geological Exploration
- Petroleum Production
- All types of Cable and Churn Tool Drilling

Try Spang today!

SPANG CABLE TOOLS

SPANG & COMPANY, BUTLER, PA.

For Sale by Dealers Everywhere

CONFIDENTIAL

MAP FILE

 # MT4

Mail Order Today

SHIPPED FROM STOCK

A metal cabinet map file—with locking doors. 112 tilting tubes. Easy to file and find maps, tracings to 60".

PATENT NO. 1610368. Other Patents Pending.

SCOTT-RICE COMPANY
610 S. Main Tulsa 3, Okla.

Handbook for Landmen

Price $25.00

A MUST for lease brokers, oil company landmen, scouts, attorneys and titlemen.

Book provides a cross-indexed reference on farmout letters, purchase agreements, inheritance, probate, property execution of leases and deeds, leasing by guardians and executors, adverse possession, prescription, limitation title, payment of rentals, dowry, vacancies, taxes, recording practices, and other related subjects. **MR. M. C. ROWOLD,** the author, has been with Humble Oil & Refining Company 26 years.

For Sale by

Society of Exploration Geophysicists
624 S. Cheyenne
Tulsa 3, Oklahoma

ANNOTATED BIBLIOGRAPHIES OF ECONOMIC GEOLOGY

Available—Vols. I-XVII (1938-1944); Vol. XIX (1946); Volume XX (1947); Volume XXI (1948); Volume XXII (1949); Volume XXIII (1950); Volume XXIV (1951); Volume XXV (1952)

XVIII (1945) in preparation.

General Index to Vols. I-X

Price $5.00 per volume anywhere in the world

ECONOMIC GEOLOGY JOURNAL INDEX TO VOLS. I-XL

Index to Vols. I-XX (1906-1926) ..$3.00
Index to Vols. XXI-XXX (1927-1935) 2.00
Index to Vols. XXXI-XL (1936-1945) 2.00

Available from:
Economic Geology Publishing Company
121 Natural Resources Building
Urbana, Illinois

Please mention GEOPHYSICS when answering advertisers

HAVE YOU EVER BEEN IN A SPOT LIKE THIS?

If your shot hole drilling takes you off the beaten path, chances are you've witnessed a predicament like this, where the driver has said "but for the grace of God and my KING Winch up front, I'd still be in there."

Day in, day out, around the world, wherever exploration goes on, KING Front-Mount Winch Assemblies are getting crews in and out of otherwise inaccessible locations . . . blizzard or flood, sand or mud, over bad roads or no roads at all.

The result of over 20 years of front-mount leadership, KING Winches are light-weight, properly balanced and ruggedly braced for years of heavy pulling.

Whether crankshaft driven for 3-speed transmissions, or power-take-off driven for 4-speed transmissions, as above, KING Winches are "factory-fit" assemblies for all popular model trucks.

At home or abroad, wherever your operations take you, you'll count on your KING "travel insurance" up front on your mobile equipment.

Koenig IRON WORKS

Write for bulletins on KING Complete Front-Mount Winch Assemblies to fit your trucks.

2214 Washington Ave. • Houston 10, Texas

3964

EUROPEAN ASSOCIATION
OF
EXPLORATION GEOPHYSICISTS

The E.A.E.G. was founded in December 1951

The aims of the Association are to promote the science of exploration geophysics by establishing contacts and encouraging co-operation and fellowship between geophysicists in Europe and elsewhere and by disseminating knowledge of the science through the agency of regular meetings and the publication of technical papers.

MEMBERSHIP

Active Members pay an annual membership fee of Neth. fls. 12.—, increased by Neth. fls. 0.50 collecting charges. In U.S. currency this charge amounts to $3.30.

Prospective Members. Anybody interested in geophysics can apply for membership by sending in an Application Form, duly filled out. Forms will gladly be supplied by the Secretary-Treasurer of the E.A.E.G. but may also be obtained through the kind assistance of the Business Manager of the S.E.G.

GEOPHYSICAL PROSPECTING

Official Journal of the European Association of Exploration Geophysicists

This journal is issued quarterly and contains articles written in English, French or German. English, however, is predominant and each article is preceded by an abstract in that language.

Active members receive the journal free of charge.

The Subscription Rate for non-members is Neth. fls. 22.—(U.S. $5.80) per annum. Single copies are available at Neth. fls. 6.—(U.S. $1.60). These rates include packing and postage and are payable in advance.

In accordance with the Terms of Affiliation with the Society of Exploration Geophysicists, members of that Society may receive the journal for the normal membership fee if subscriptions are entered through the Business Manager of the S.E.G.

A limited quantity of previous issues is still available.

All communications to be directed to:

THE SECRETARY-TREASURER E.A.E.G.

30, C. VAN BYLANDTLAAN • THE HAGUE • NETHERLANDS

LET MAYES-BEVAN SEISMOGRAPH AND
GRAVITY METER SURVEYS ACCURATELY
MARK THE "MOST LIKELY AREA" IN
YOUR OIL PROVINCE.
MAYES-BEVAN
GRAVITY METER
M
B
SEISMOGRAPH
COMPANY
KENNEDY BLDG. • TULSA, OKLA.

The finest that research can develop

SPECIFY "ALL MISSION" MUD PUMP PARTS TO YOUR GEOPHYSICAL OR OIL FIELD SUPPLY STORE

MISSION MANUFACTURING CO.

P. O. BOX 4209 • HOUSTON, TEXAS

Export Office: 30 Rockefeller Plaza, New York

GRAVIMETRIC

AND

MAGNETIC

- SURVEYS
- REPORTS
- REVIEWS

•

KLAUS
EXPLORATION CO.

PHONE 2-1551 · BOX 1617 · LUBBOCK, TEXAS

BIG SIZE SAVINGS ON SMALL SIZE PUMPS!

MacCLATCHIE GEOPHYSICAL PUMP PARTS!

For the fluid end of your small size geophysical pumps, here's a quick line-up of MacClatchie replacement parts *engineered* to give you maximum dependable service under the tough conditions of exploration work...

MacClatchie Type "GS" Pump Piston

—for general field service in all makes and sizes of pumps and for all rod tapers. Lip design of rubbers allows expansion under fluid pressure, insuring leak-proof operation. Piston easily renewed by replacing worn rubbers, using end plates and center spool over again.

MacClatchie Type "FR" Pump Piston—A *one-piece* piston with *no metal* to touch the liner bore... no end plates... no lock rings... no separate body. The best piston available at an economy price—made in most popular sizes and rod tapers.

MacClatchie Type "GS" Wing Guide Valve

—Engineered with full opening valve seat to permit free flow of cuttings, heavy slurries and foreign material without sticking. Easily disassembled to replace worn insert by removing single cap screw.

MacClatchie Type "A" Center Guide Valve—Body has center guide to fit in cross-bar type valve seat. Assures a well-guided valve, yet is designed to permit free fluid flow under all pressures. Insert easily changed by removing cap which is threaded to valve body.

MacClatchie Type "A" Wing Guide Valve—A quality valve made especially for geophysical service where high pressures are encountered. Wing guides provide for a full-opening valve seat that permits free fluid flow at all volumes and pressures. Disassembly for insert renewal same as for center guide valve.

MacClatchie Liners and Rods—MacClatchie one-piece hardened and honed liners are made from steel forgings, scientifically heat treated and mirror-honed. O. D. is machined for perfect fit. Chrome plated liners also available.

MacClatchie Rods are made in all API and manufacturer's tapers of carburized and hardened alloy steel, ground to a smooth finish to prevent scoring and corrosion. Also available chrome plated. Furnished complete with rod and jam nut.

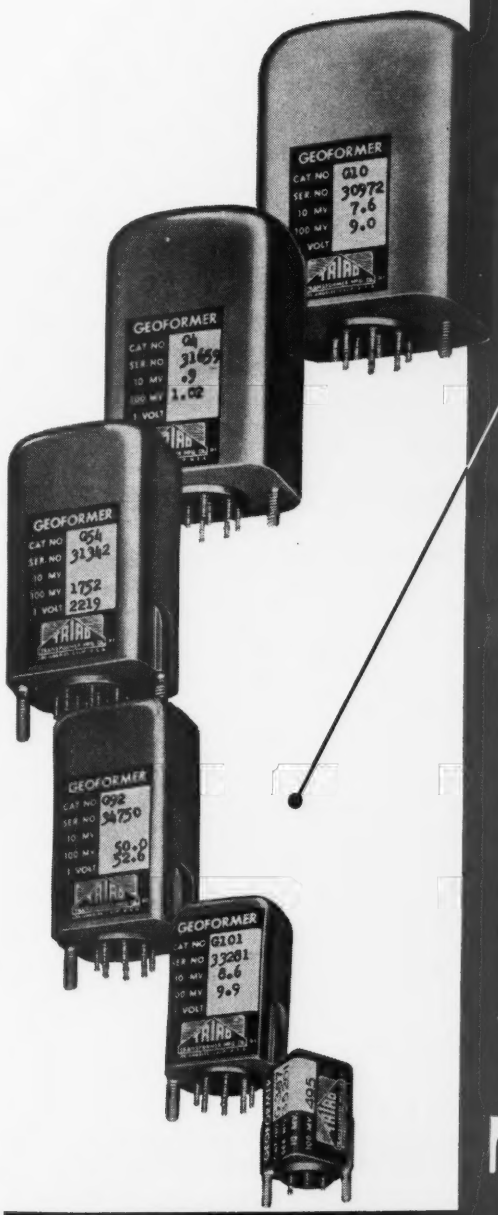
Write for Descriptive Literature and Specifications

MacCLATCHIE MANUFACTURING COMPANY

A Subsidiary of Grant Oil Tool Co.

MAIN OFFICE & PLANT: COMPTON, CALIFORNIA

THE SYMBOL OF QUALITY



TRIAD

Exceptional Low Frequency Response • Small Size • "Climatite" Treatment • Nickel Finish • Multiple Magnetic Shielding • High Inductance

TRIAD GEOFORMERS

Triad "Geoformers" (Geophysical Transformers) combine all the qualities and features necessary for sustained trouble-free service in geophysical prospecting equipment. From "Trialloy" shielding to hermetic sealing they are created to do a specific job—not an adaptation of standard transformers. Geoformers are manufactured in accordance with MIL-T-27 specifications as well as Triad's own extremely high standards of quality control.

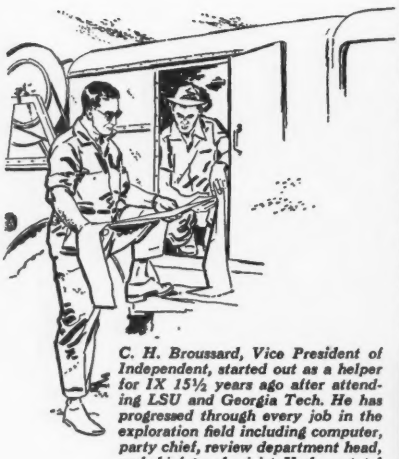
*The improved and exclusive vacuum impregnation process used on all Triad Transformers.

Write for Catalog TR-54 which describes and illustrates the complete line of Triad Electronic and Geophysical Transformers.

TRIAD TRANSFORMER CORP.

WEST COAST ELECTRONIC MANUFACTURERS ASSOCIATION

6803 Redwood Ave., Venice, Calif.



C. H. Broussard, Vice President of Independent, started out as a helper for IX 15½ years ago after attending LSU and Georgia Tech. He has progressed through every job in the exploration field including computer, party chief, review department head, and chief geophysicist. He has a total of 17 years experience in geophysical work.

Experience, Equipment and Modern Techniques are the keys to your Exploration Success

Independent Exploration Company has contributed generously to the development of new equipment and modern techniques during the 20 years in which it has served the oil industry.

Now one of the oldest and most experienced exploration contractors in the business, Independent believes that experienced Party Chiefs hold a key to your exploration success. Independent's crews under the supervision of Party Chiefs with an average of 16 years service, have served more than 100 important oil producers.

POINTING THE WAY IXC FOR THE DRILL

Independent's Experience Merits Your Confidence

Independent EXPLORATION COMPANY

Geophysical Surveys 1973 WEST GRAY ★ HOUSTON, TEXAS

ESTABLISHED 1932

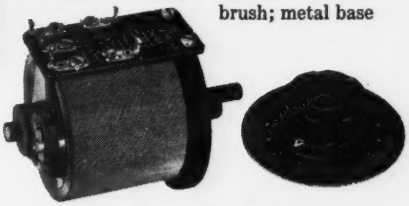
Twice the Power

For the Same Price

with the NEW

ype V-2 Variac®

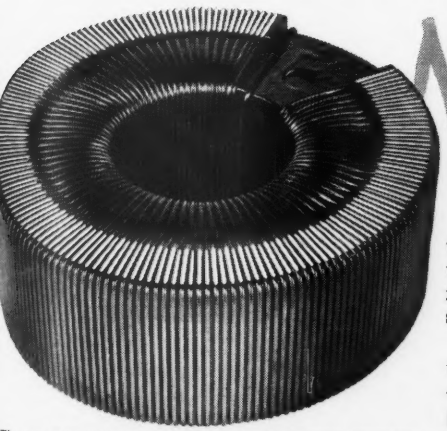
Brush and track on face of winding instead of periphery, for panel mounting, dial reversible to read 0–115 or 0–135 volts, output; ⅜-inch insulated shaft; improved terminal plate with circuit and connections clearly shown; G-R unit brush; metal base



opular "V" series of VARIAC continuously-adjustable autotrans-rmers. With a power rating of *twice* that of the Type 200-B, it is intended ventually to supplant the latter.

The Type V-2 represents a considerable improvement over the 00-B, making it even more adaptable to a wide variety of applications here a relatively low-power, moderately-priced, a-c voltage control with l of the latest exclusive VARIAC features is needed. Its electrical and echanical features include:

- ★ New DURATRAK brush-track coating
- ★ Load rating of 0.345 kva (instead of 0.17 kva)
- ★ Output voltages continuously adjustable from 0 to 135 v, or 0 to 115 v.
- ★ Line frequency 50 to 60 cycles; no load loss at 60 c.: less than 3.5 watts
- ★ Standard mounting holes (interchangeable with Type 200-B)
- ★ Considerably less panel space
- ★ Metal Base for improved cooling and added strength
- ★ More rugged stops
- ★ G-R Unit Brush construction
- ★ Terminal board with circuit and connections clearly shown
- ★ Molded knob-pointer and reversible dial plate for panel installation
- ★ Meets applicable requirements of Military Specification for Transformers: MIL-T-27
- ★ **Moderate Price: $12.50**



The new DURATRAK coating is one of the most important provements in VARIACS; another step in the continuing ocess of development which makes the VARIAC the best voltage control available

NOW ALL "V" TYPE VARIACS HAVE NEW Duratrak CONSTRUCTION

for Increased Performance

Even Longer Life

The new DURATRAK brush-track coating eliminates all brush track oxidization problems which formerly might become critical under severe conditions of operation.

DURATRAK construction adds these features to increase the utility of VARIACS:

Long Life — *insures a life as long as that of fixed-ratio power transformers operated at rated loads*

Unaffected By Surges — *VARIACS with DURATRAK will withstand initial surges as high as ten times rated current*

Minimum Maintenance — *the brush track will not deteriorate under normal operation — only maintenance needed is occasional wiping of track with alcohol-moistened rag*

Write for the NEW VARIAC BULLETIN for Complete Specifications

GENERAL RADIO Company

275 Massachusetts Avenue, Cambridge 39, Massachusetts, U. S. A.

90 West St. NEW YORK 6 920 S. Michigan Ave. CHICAGO 5 1000 N. Seward St. LOS ANGELES 38

Admittance Meters ☆ Coaxial Elements ☆ Decade Capacitors
Decade Inductors ☆ Decade Resistors ☆ Distortion Meters
Frequency Meters ☆ Frequency Standards ☆ Geiger Counters
Impedance Bridges ☆ Modulation Meters ☆ Oscillators
Variacs ☆ Light Meters ☆ Megohmmeters ☆ Motor Controls
Noise Meters ☆ Null Detectors ☆ Precision Capacitors
Pulse Generators ☆ Signal Generators ☆ Vibration Meters ☆ Stroboscopes ☆ Wave Filters
U-H-F Measuring Equipment ☆ V-T Voltmeters ☆ Wave Analyzers ☆ Polariscopes

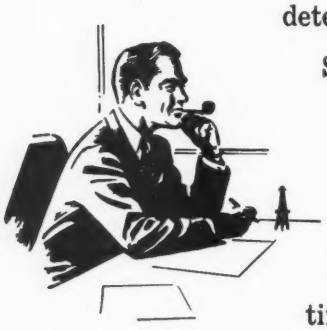
On what..

DO YOU BASE YOUR DRILLING DECISION?

Facts show that the search and the find is more certain when based on the scientifically accurate and dependable results of a good seismic survey.

BUT... the value of survey results can be determined only *after* the survey is made.

So *how do you buy a good seismic survey?*

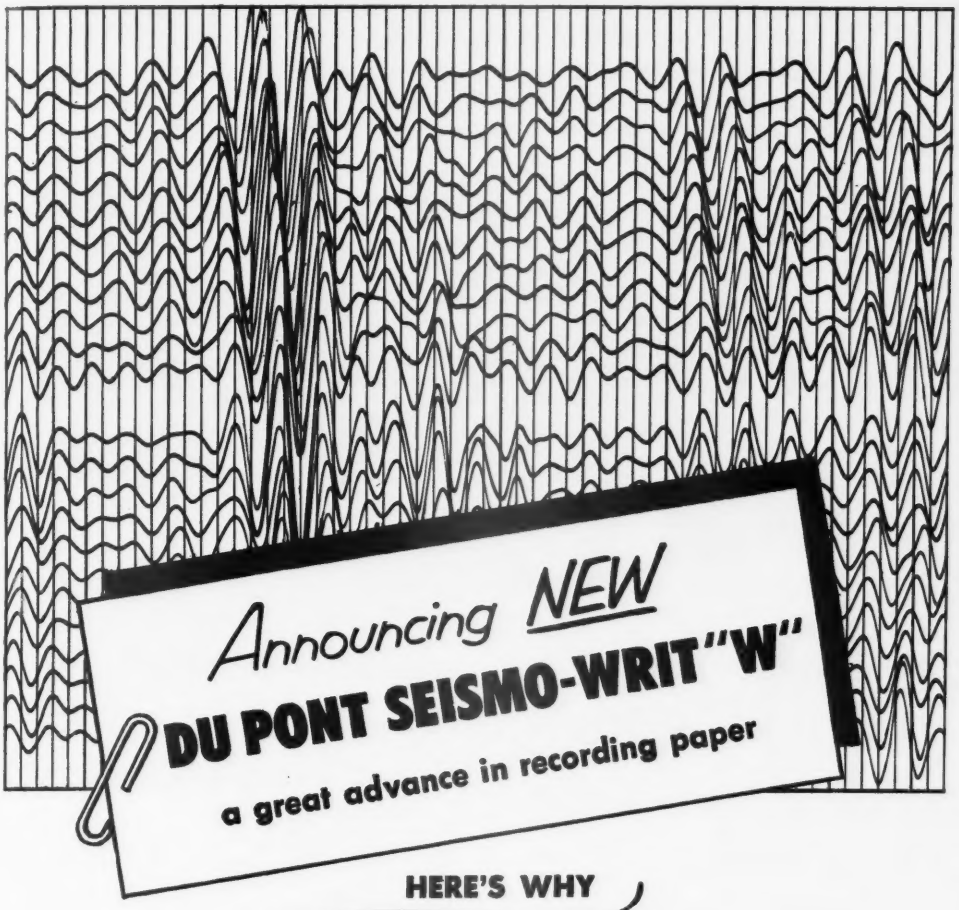


Depend on a survey firm that offers you: the best of modern equipment intelligently used by capable personnel; the close supervision of field crews by competent seismologists; and the scientifically skilled interpretation of data.

Depend on a firm of proven record for integrity of operation and dependable survey results....

Rayflex EXPLORATION COMPANY
DALLAS, TEXAS

M. C. Kelsey E. F. McMullin J. F. Rollins G. W. Fisher J. C. Spiers



1. It's tougher. Wet or dry, this *all-rag* stock's stronger than ordinary papers. Test it any way you want . . . Du Pont Seismo-Writ "W" can take it!

2. It's thinner. The same size spool holds more paper . . . you get longer running time in the machine before changing rolls and 60% more material in your files.

3. It's lighter. Because "W" weighs less than other papers, it's easier to carry, easier to ship.

4. It's easier to mark. The smooth, semi-matte surface takes ink or pencil marks readily . . . is easier to interpret.

5. It's translucent. To make duplicate charts, you simply print through.

And *new* "W" Paper retains everything you like about standard Seismo-Writ: contrasty, legible records under tough conditions . . . easy-to-interpret quality . . . ample exposure latitude every time . . . and high "no-stain," "no-swell," "no-curl" properties. So, to simplify and save on every step of the operation, test Du Pont Seismo-Writ "W" on your next job. Packed in moisture-proof polyethylene, it's available at your supplier's. Contact him soon. And for more details about this great new development, ask your Du Pont representative, or write: E. I. du Pont de Nemours & Co. (Inc.), Photo Products Department, Wilmington 98, Delaware.

DU PONT
SEISMIC PRODUCTS

DU PONT
REG. U.S. PAT. OFF.

BETTER THINGS FOR BETTER LIVING
. . . THROUGH CHEMISTRY

Direct to You . . .

from our shelves

DISTRIBUTORS FOR:

Eastman Kodak

Du Pont & Peerless Photo Products

Survey Flaggings

Dual (2-ply) Recording Paper for producing original and copy simultaneously

IMMEDIATE DELIVERY ON:

- Recording Papers and Chemicals
- Copy Papers and Printers for record copying
- Custom Stainless Steel Tanks
- Survey Flaggings
- Loading Poles
- Balloons for Marine Exploration
- Alumafold Field Tables

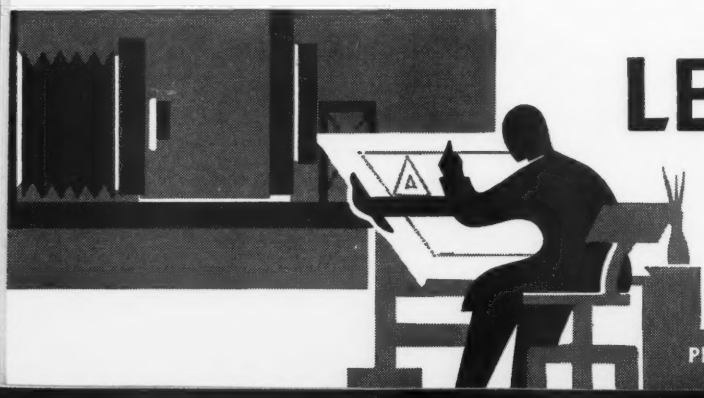
THREE STORES CONNECTED BY TELETYPEWRITER SERVICE

Order placed with any of our stores will be shipped the same day from the store nearest your crew

183 Parkhouse St.—Dallas
Phone STerling 1232

317 E. 4th St.—Tulsa
Phone 54-4269

1013 Bell Ave.—Houston
Phone CApital 6060



LEW WENZEL

& COMPANY

PHOTOGRAPHIC METHODS APPLIED TO INDU

PERMA-FLAG

The Permanent Plastic Survey Flagging

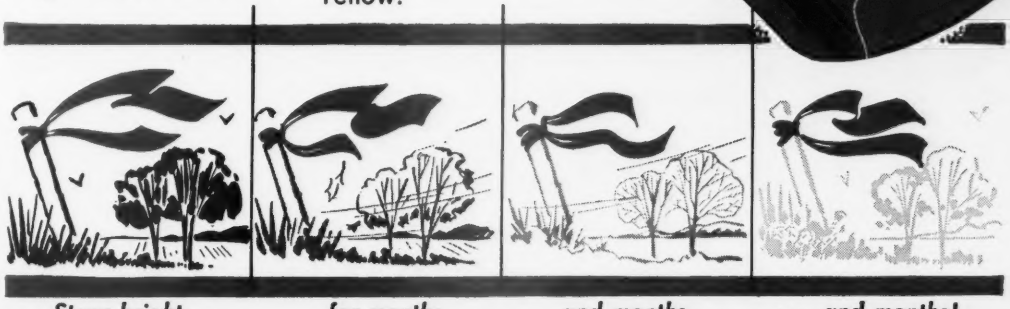
It's Better! Bright, highly reflective, non-fading colors.

More for Your Money! Rolls are 330 feet long — 30 feet longer!

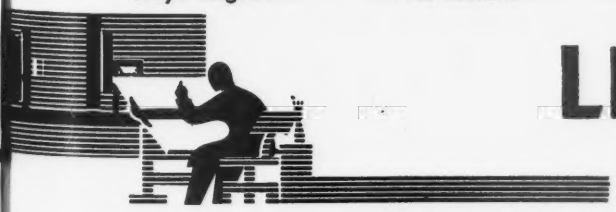
It Costs Less! In cartons of 12 rolls of one color, 80c per roll. Less than 12 rolls of one color, 85c per roll. 11" wide by 110 yd. rolls for BIG flags, $6.90.

It's Tough! It ties well to —40°F. . . . won't fray, fade or "shoe string."

Colors Available: Red, White, Blue, Orange and Yellow.



Stays bright . . . *. . . for months . . .* *. . . and months . . .* *. . . and months!*



LEW WENZEL & COMPANY

319 E. Fourth St. — Tulsa, Okla. • Offices in Dallas and Houston

PERMA-FLAG AVAILABLE FROM . . .

Lancaster Supply Company
913 Powell Street
San Angelo, Texas

Seismic Service Supply Limited
1318 Ninth Avenue, East
Calgary, Alberta, Canada

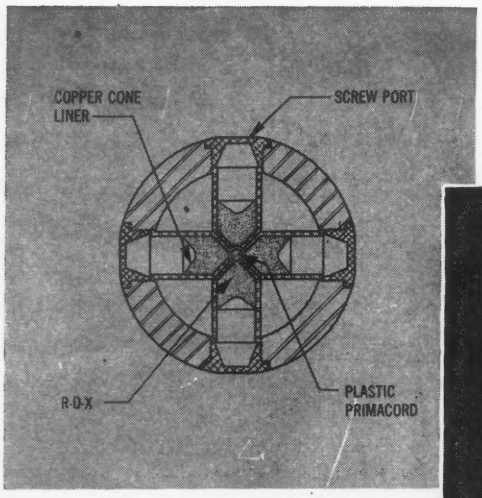
Surveyors Service Company
2021 South Grand Avenue
Los Angeles 7, California

Midwestern Pacific Sales Company
2514 First Avenue North
Billings, Montana

W. H. Bit & Supply Company
P.O. Box 214
Riverton, Wyoming

Milne Explosives Company
901 Stone Street
Great Bend, Kansas

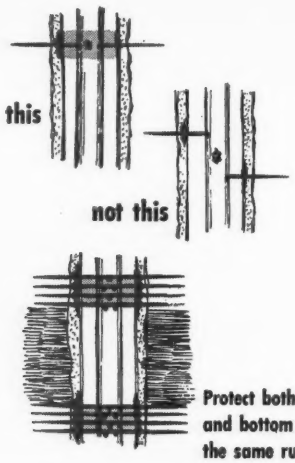
Basin Oil Field Supply, Inc.
P.O. Box 211
Wolf Point, Montana



The diagram above shows the charge arrangement in the "4-Way" gun.

WATER-PROOFING

the pay zone with Lane-Wells new "4-way" gun



Protect both top and bottom on the same run

This new KONESHOT Gun was developed for just one purpose—to help insure the success of "block-squeezing" to protect the pay. Reports from the field indicate that the "4-Way" gun is giving excellent results. We call it the "4-Way" gun because, for the first time, engineering design puts 4 Koneshot charges in the *same plane,* firing four shots all on the same level, 90 degrees apart. Thus, when cement is forced through the perforations into the crevices of a zone of weakness, or along the bedding plane, it tends to form a continuous sheet, or pancake, completely encircling the well bore—a solid, one-piece shield that effectually halts fluid migration from either above or below. Also, for still greater efficiency, the "4-Way" gun pattern is available in Lane-Wells famous semi-selective F-2 gun, so you can perforate both above and below the pay *on one run.*

Lane-Wells gun design gives you better squeeze jobs... accurate depth measurements put the shots in the exact spot ordered ...and get the job done right...the first time—call

Tomorrow's Tools-Today!

LANE WELLS COMPANY

General Offices, Export Office, Plant • 5610 So. Soto St., Los Angeles 58

AX-607 LOS ANGELES • HOUSTON • OKLAHOMA CITY • LANE-WELLS CANADIAN CO. IN CANADA • PETRO-TECH SERVICE CO. IN VENEZUELA

now hear this!

ADVANCED OFFERS

. . . a completely equipped crew to handle your off-shore surveys. These experienced men are prepared to give the same individual attention, the same high quality service familiar with Advanced's land crews. Whatever your geophysical survey needs, Advanced is now equipped to handle them quickly, efficiently, accurately, whether on land or off-shore.

ADVANCED EXPLORATION CO., INC.
3732 Westheimer
Houston, Texas

ADVANCED EXPLORATION COMPANY INC. HOUSTON, TEXAS

PRINCETON UNIVERSITY PRESS BOOKS

Of Interest to Geophysicists

Oil in the Soviet Union

By Heinrich Hassmann, translated by Alfred M. Leeston
Foreword by E. DeGolyer

Russia's economic and military strength depends to a large extent upon its oil resources and oil industry, about which little is known. Dr. Hassmann has collected material that is not readily available, has carefully analyzed it, and has presented his survey in well-organized, readable form. He takes up the industry's history, its major regions, and its various problems.

Dr. Leeston has added much new material, and E. DeGolyer, one of America's foremost petroleum geologists, has written the foreword.

186 pages. Maps. $3.75

Early Days of Oil

By Paul H. Giddens

From the priceless collection of 3000 John A. Mather photographs preserved in the Drake Museum, Paul Giddens has chosen 365 to record pictorially the development of the oil industry from 1860 through 1892. Boom towns and disasters, early wells, primitive equipment, transportation, and outstanding characters of the era were all photographed by Mather as he followed the excitement of the infant industry. The pictures are accompanied by an historical running narrative.

365 photographs. $6.00

World Geography of Petroleum

Edited by Wallace E. Pratt and Dorothy Good

For this comprehensive discussion of world oil the American Geographical Society has prepared 50 new maps, and a corps of expert petroleum geologists and administrators from the world's important oil-bearing regions have contributed detailed descriptions based largely on on-the-spot knowledge.

"The most authoritative and informative book on this subject at present available."—*American Scientist.*

530 pages. 98 plates. 30 tables. 60 figures. $9.00

The Tectonics of Middle North America

By Philip B. King

Treats the tectonics, or architecture, of the rock formations of middle North America east of the Cordilleran system, how these formations were created, and their modifications by crustal unrest. "The material is presented very concisely and logically. A maximum amount of information is gained with minimum effort, and that alone is sufficient recommendation for reading this volume." *Geophysics.*

224 pages. 52 maps. $3.75

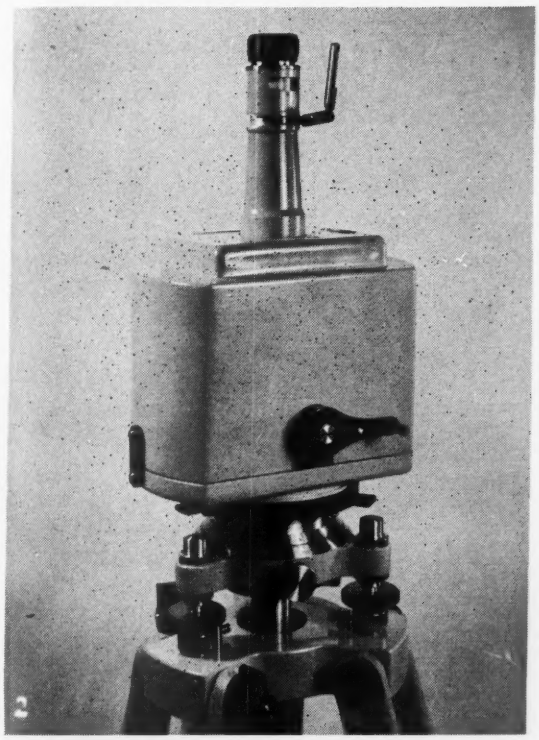
Postpaid in U.S.A. ***No handling charges When purchased from*** ***50¢ foreign postage***

SOCIETY OF EXPLORATION GEOPHYSICISTS
624 South Cheyenne **Tulsa 3, Oklahoma**

For Results Use

RUSKA MAGNETOMETERS

TEMPERATURE COMPENSATED SYSTEMS WITH SAPPHIRE KNIFE EDGES



TYPE V—Vertical Magnetic Field Balance

TYPE H—Horizontal Magnetic Field Balance

TYPE VR—Vertical Magnetic Recording Balance

TYPE HR—Horizontal Magnetic Recording Balance

Standard Sensitivity

10 gamma per scale division—visual

10 gamma per millimeter—recorded

"SCOUT"—A light-weight vertical reconnaissance magnetometer

Standard Sensitivity

25 gamma per scale division

Also: HOTCHKISS TYPE SUPERDIP

A MAGNETOMETER IS ONLY AS GOOD AS THE EXPERIENCE WHICH GOES INTO ITS MANUFACTURE: Ruska has been engaged in the design, development and manufacture of Magnetometers and other magnetic instruments since 1928.

THE QUALITY AND COST OF A MAGNETIC SURVEY IS DETERMINED BY THE ACCURACY, RELIABILITY AND DURABILITY OF THE INSTRUMENT USED: Ruska Magnetometers are built to remain accurate and to stand hard use. Ruska Instrument Corporation maintains its own Magnetic Field Station where Magnetometers and Magnetic Observatory Instruments are calibrated for all parts of the world.

(Patented or patents pending in all principal countries)

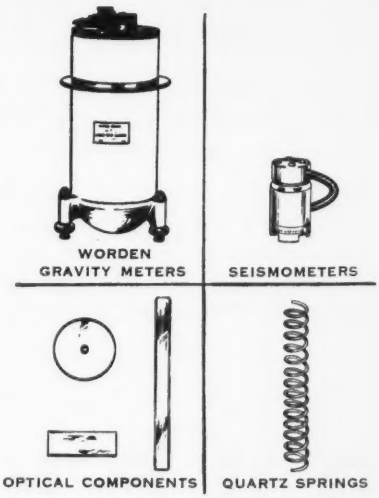
ASK FOR ILLUSTRATED CATALOG

RUSKA INSTRUMENT CORPORATION

4607 MONTROSE BLVD. HOUSTON 6, TEXAS

HOUSTON TECHNICAL LABORATORIES IS NOW A SUBSIDIARY OF TEXAS INSTRUMENTS INCORPORATED

Here at Houston Technical Laboratories we believe that hitching our wagon to a star is still good business. That's why we're so happy to announce our affiliation with Texas Instruments Incorporated of Dallas. It is fitting that HTL—producer of the famous Worden Gravity Meter, specialized optical components and quartz springs—has joined with TI, manufacturer of seismic, electronic and electro-mechanical equipment. TI's wide range of seismic equipment has been proved in the worldwide service of Geophysical Service Inc. field crews. HTL will manufacture all seismic instruments formerly produced at TI in Dallas. Keep an eye on this HTL-TI combination. It's a rising star in the field of geophysical instrumentation.



HOUSTON TECHNICAL LABORATORIES
A SUBSIDIARY OF TEXAS INSTRUMENTS INCORPORATED
2424 BRANARD • HOUSTON 6, TEXAS

FOR ACCURATE RECORDINGS...

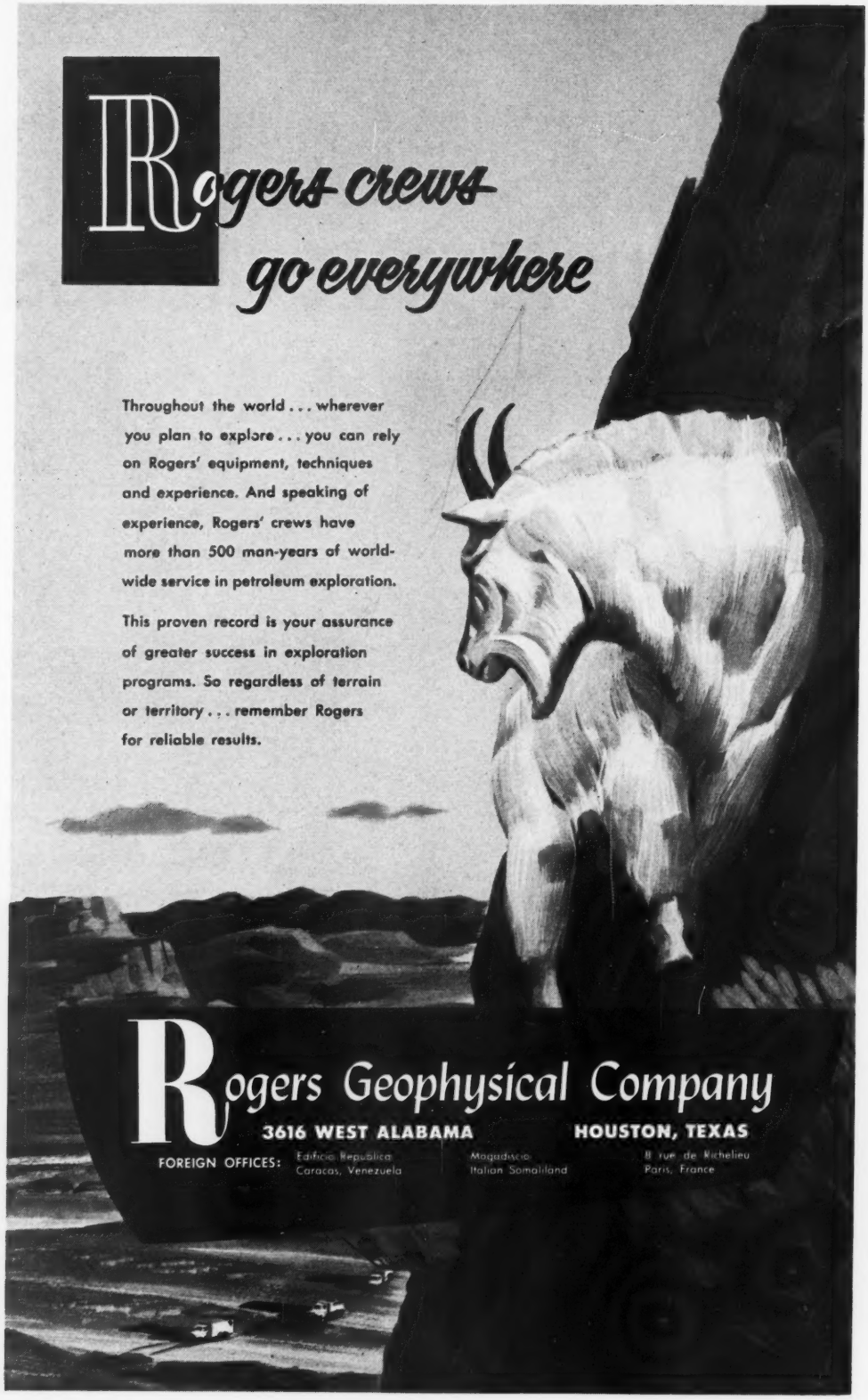
To obtain reliable subsurface petroleum surveys, seismic prospecting crews demand accuracy to the "nth" degree in their field equipment—and especially in their explosives and E.B. caps. Hercules has pioneered in the development of many special seismograph products, including: the Vibrogel® series...which detonate under severe water pressures; Spiralok® . . . rigid dynamite cartridge assembly that saves time in loading; and the Vibrocap® SR series...detonators that reduce the danger of premature firing by static electricity, and eliminate "time-lag" between firing and actual detonation of explosives charge. Hercules has the right types of explosives and the service facilities to expedite their use in petroleum projects, coal mining, metal mining, quarrying, and construction.

HERCULES POWDER COMPANY
INCORPORATED

Explosives Department, 917 King St., Wilmington 99, Del.

Birmingham, Ala.; Chicago, Ill.; Duluth, Minn.; Hazleton, Pa.; Joplin, Mo.; Los Angeles, Cal.; New York, N. Y.; Pittsburgh, Pa.; Salt Lake City, Utah; San Francisco, Cal.

XR53-6


Rogers crews go everywhere
Throughout the world . . . wherever you plan to explore . . . you can rely on Rogers' equipment, techniques and experience. And speaking of experience, Rogers' crews have more than 500 man-years of world-wide service in petroleum exploration.
This proven record is your assurance of greater success in exploration programs. So regardless of terrain or territory . . . remember Rogers for reliable results.
Rogers Geophysical Company
3616 WEST ALABAMA HOUSTON, TEXAS
FOREIGN OFFICES: Edificio Republica Caracas, Venezuela
Mogadiscio Italian Somaliland
8 rue de Richelieu Paris, France

OIL MEANS SCIENTIFIC PROGRESS

Years of research . . . endless experiments . . . triumph after failure. And the magic of modern science gives us new uses every year for petroleum to make ours a better way of life. Schlumberger Services have played a major role in the oil development of the United States and Canada. They have materially reduced the cost of oil exploration, and have pointed the way to numerous discoveries.

And Schlumberger means Service

Schlumberger Well Surveying Corp. • Houston, Texas

HALOID RECORD

SEISMOGRAPH RECORDING PAPER IS FAVORED BY CRITICAL GEOPHYSICISTS

HALOID RECORD is plenty tough. It resists heat and withstands moisture. It provides sharp lines and legible contrast. Its processing advantages and consistently uniform performance even under the most adverse conditions of field and laboratory, make it the ideal paper for this work.

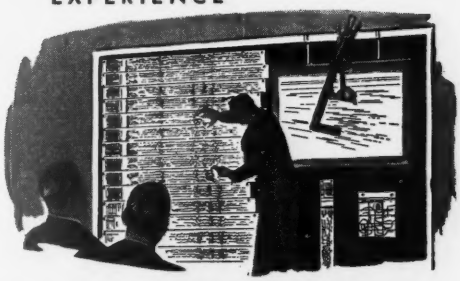
For superior seismographic recordings that successfully combine photographic excellence with an amazing ability to withstand abuse, use Haloid Record—the paper that's favored by critical geophysicists.

THE HALOID COMPANY

54-10 Haloid St., Rochester 3, N.Y.

SEI

EXPERIENCE



INTERPRETATION

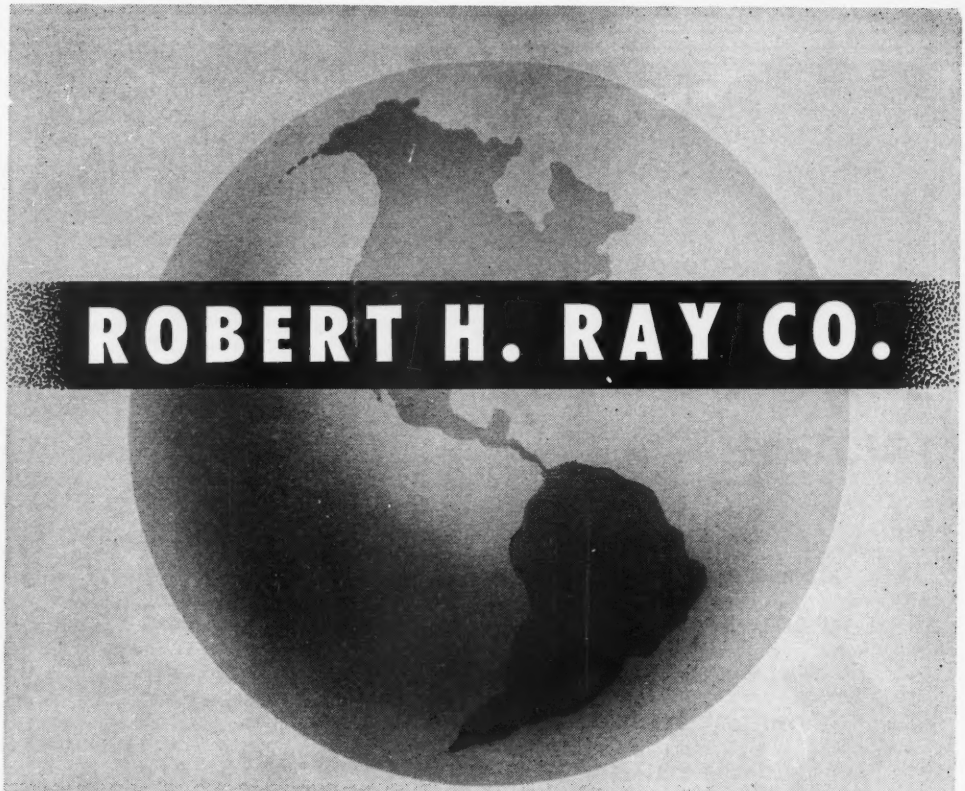
For twenty-two years, SEI has specialized in sub-surface studies of the domestic oil provinces . . . from Canada to the Gulf. Numerous innovations in instrumentation, interpretation, and field technique have kept SEI in the forefront. For example, in difficult areas, SEI has been a pioneer in the use of patterns of multiple shot holes and geophone arrays.

Your exploration program is in capable hands at SEI.

TECHNIQUE

SEISMIC EXPLORATIONS INCORPORATED

1007 SOUTH SHEPHERD • HOUSTON, TEXAS



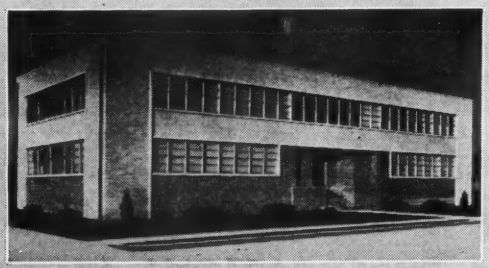
ROBERT H. RAY CO.

"WORLD WIDE IN OPERATIONS"

GEOPHYSICAL ENGINEERING

Seismic · Magnetic · Gravity

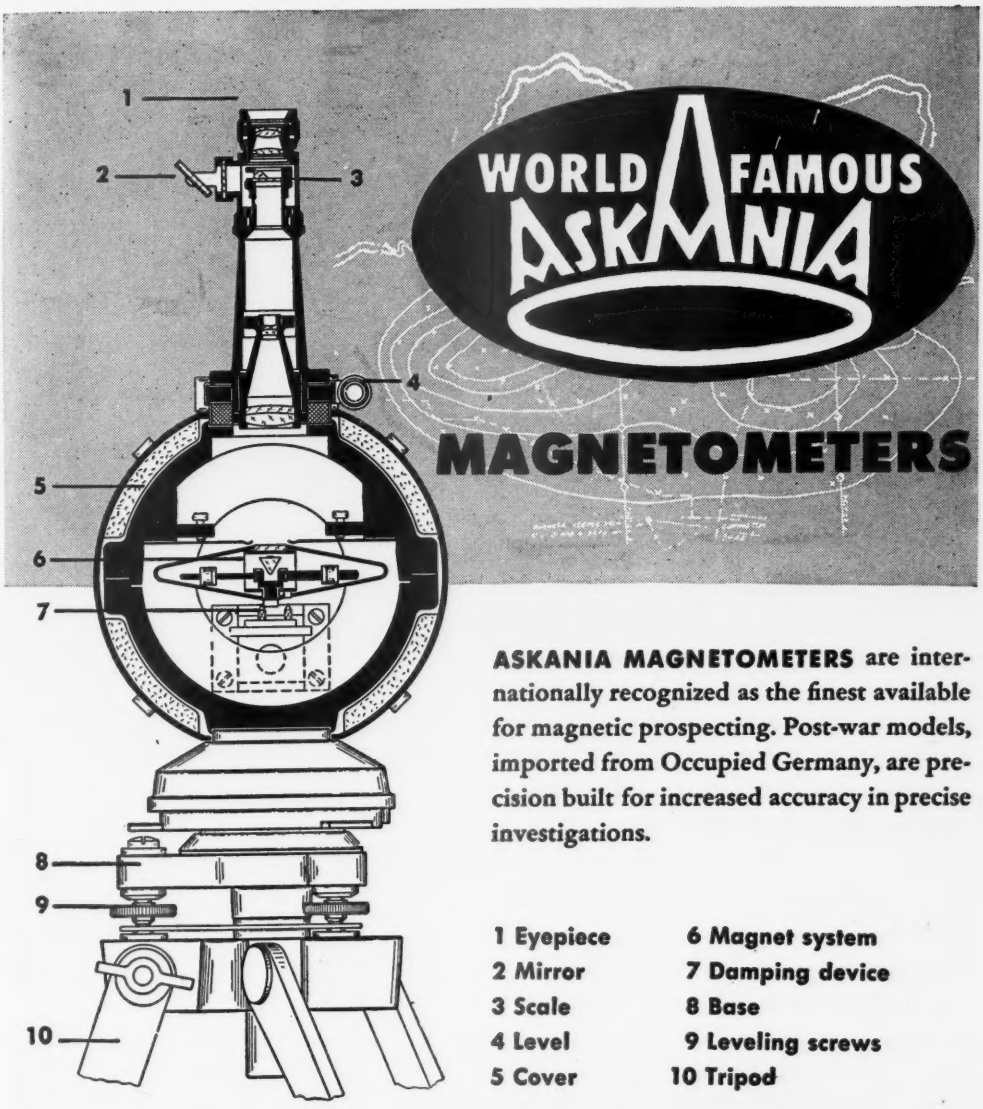
SURVEYS



ROBERT H. RAY
ROBERT S. DUTY JR.

JACK C. POLLARD
NORMAN P. TEAGUE

2500 BOLSOVER RD. • HOUSTON, TEXAS



ASKANIA MAGNETOMETERS are internationally recognized as the finest available for magnetic prospecting. Post-war models, imported from Occupied Germany, are precision built for increased accuracy in precise investigations.

1 Eyepiece	6 Magnet system
2 Mirror	7 Damping device
3 Scale	8 Base
4 Level	9 Leveling screws
5 Cover	10 Tripod

For complete details write...

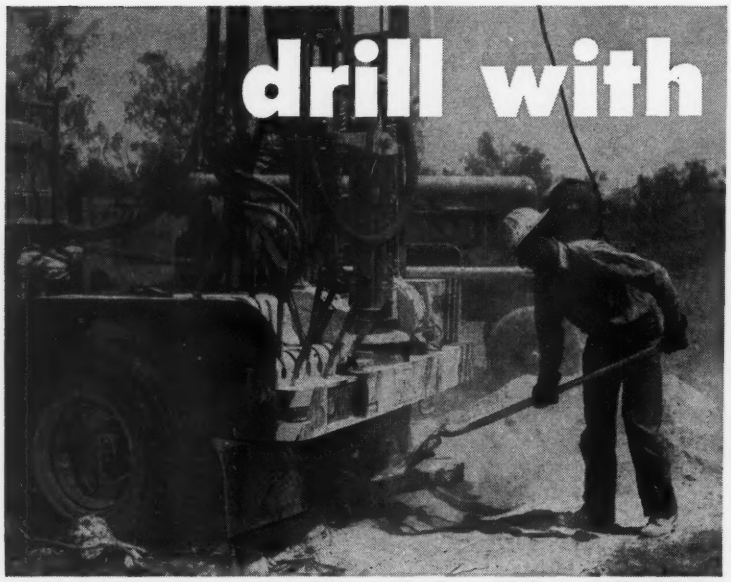
HEILAND RESEARCH CORPORATION

Exclusive U. S. Representatives

130 East Fifth Avenue
Denver, Colorado

dependable instruments
Heiland
DENVER

Please mention GEOPHYSICS when answering advertisers



Air drilling in West Texas with the new TI Shot Hole Rig.

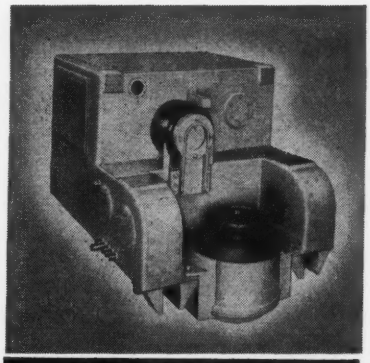
use TI's versatile Shot Hole Rig!

IN WATER-SCARCE AREAS, air drilling with TI's versatile, portable Shot Hole Rig is solving the tough problem of thirsty formations. Drilling with air—and TI's new drill—removes the cuttings from the hole quickly and economically.

And whatever the area—dusty *or* damp—the sealed-unit construction of the new INTEGRATED POWER DRIVE protects the machinery. Gears, chains, clutches, and other moving parts are completely sealed in a single case and continuously spray-lubricated with *filtered* oil.

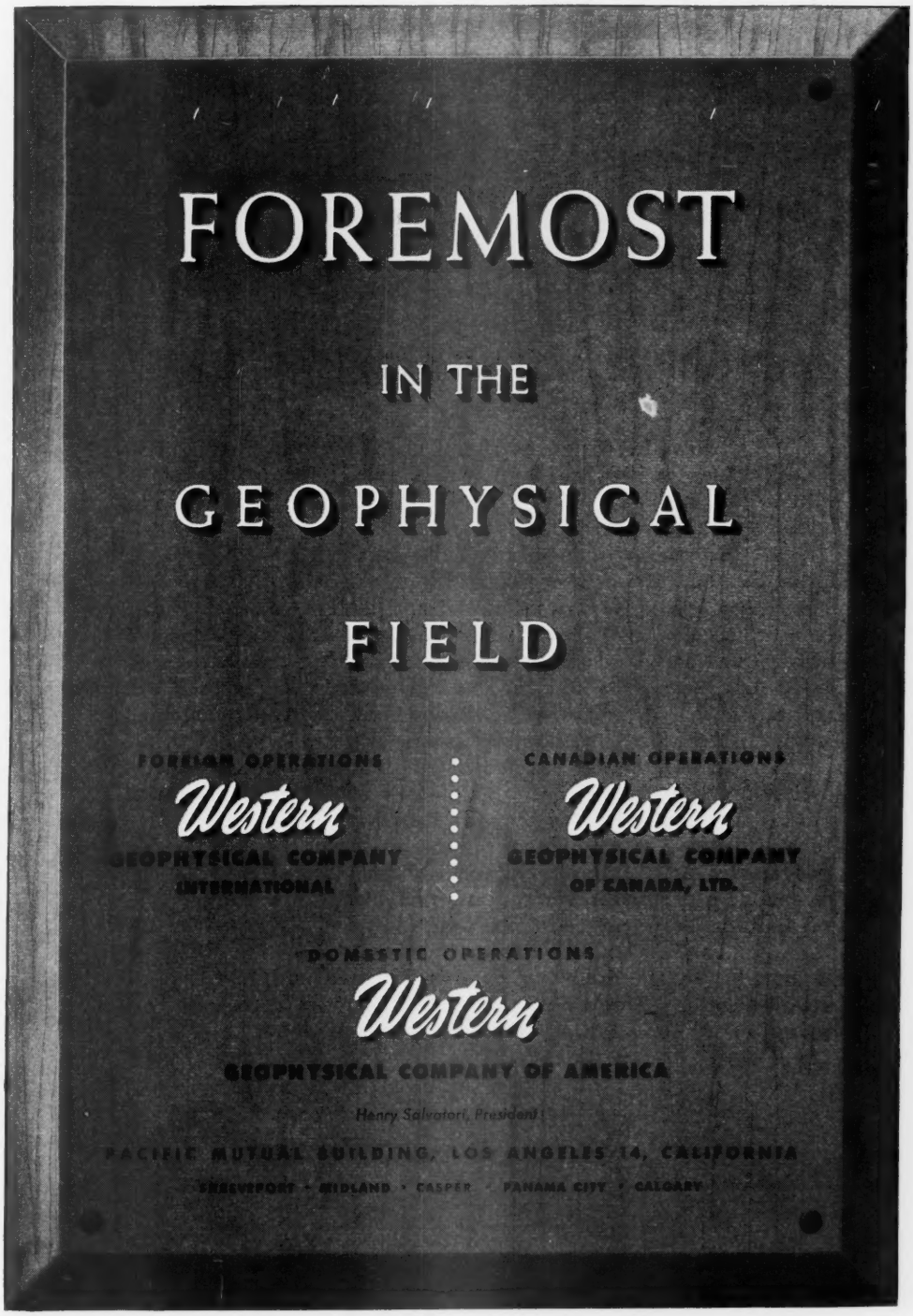
For any drilling problem—whether it calls for air, water or casing drilling—the TI Shot Hole Rig will give you lower cost per foot of hole. Write *today* for complete literature on this TI drill.

TEXAS INSTRUMENTS
INCORPORATED
6000 LEMMON AVENUE DALLAS 9, TEXAS



NEW INTEGRATED POWER DRIVE

Long life and low maintenance costs are inherent in the sealed-unit construction of the INTEGRATED POWER DRIVE, heart of the TI drill. All the components necessary for the transfer and control of power have been brought together in a *single* case with centrally located controls. Rotary table, pull down drive, kelly hoist, hoist drum, and pump drive are so integrated with the primary power drive that transfer of power for *all* drilling operations is accomplished in a *single sealed unit.*


FOREMOST
IN THE
GEOPHYSICAL
FIELD
FOREIGN OPERATIONS
Western
GEOPHYSICAL COMPANY
INTERNATIONAL
CANADIAN OPERATIONS
Western
GEOPHYSICAL COMPANY
OF CANADA, LTD.
DOMESTIC OPERATIONS
Western
GEOPHYSICAL COMPANY OF AMERICA
Henry Salvatori, President
PACIFIC MUTUAL BUILDING, LOS ANGELES 14, CALIFORNIA
SHREVEPORT • MIDLAND • CASPER • PANAMA CITY • CALGARY

ARE YOU HAPPY ABOUT YOUR SHOT HOLE COSTS?

Their Bit Records Prove Faster Footage at Lower Bit Cost Per Foot With HAWTHORNE *"Blue Demon"* BITS

You've heard lots of claims about building better bits . . . bits that cost less . . . bits that drill more . . . but the real comparison shows up on your bit record . . . your own impartial test . . . your own PROOF.

No competitive bit CAN compare with Hawthorne "Blue Demon" Bits on the basis of bit cost per foot of hole. The reason is simple. Hawthorne "Blue Demons" are low-cost finger type replaceable blade rock cutter bits . . . with fingers specially heat treated and hard faced with non-shattering tungsten carbide. They stay sharp and hold gage as they wear. They're then discarded and replaced with a new set of blades — factory controlled bit service, on the drill, without retipping or rebuilding.

"Blue Demons" get considerably more footage faster in soft and sticky formations . . . and drill with equal efficiency 90% of the medium and hard stringers formerly requiring roller bits. You save in actual bit cost, in faster penetration, and in round trip time formerly required to change bits between formations. You spend more time on bottom — lowering cost per foot.

That's why so many cost-conscious shot hole drillers have made their own comparison tests, and now standardize on "Blue Demons" . . . one bit body used with many sets of long lasting replaceable blades.

WRITE FOR ILLUSTRATED CATALOG

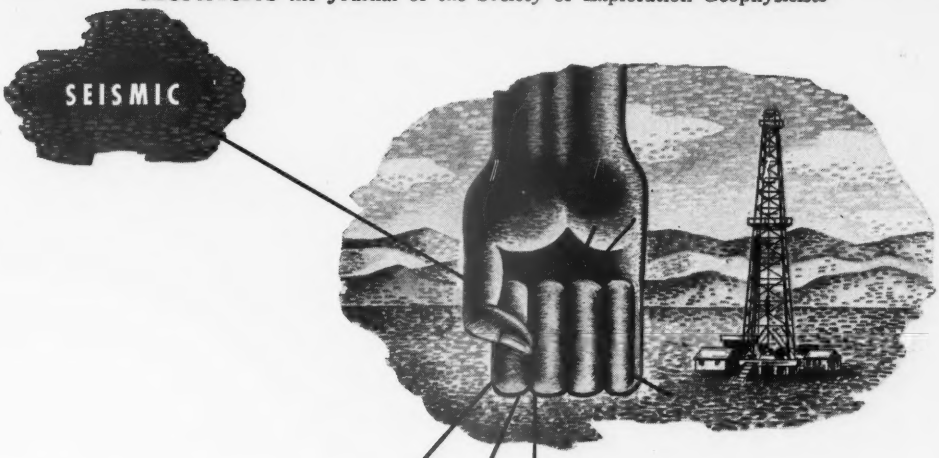
HERB J. HAWTHORNE INC.

P. O. BOX 7366, HOUSTON 8, TEXAS

Our Business Is Better Shot Hole Bits and More Economical Bit Service — Test and Compare

U. S. PATENT 2,615,684
OTHERS PENDING

4665



MAGNETIC

GRAVITY

29 YEARS...
of world-wide
Geophysical Experience
go into
every job
we undertake

Petty
GEOPHYSICAL ENGINEERING COMPANY
SAN ANTONIO, TEXAS
SEISMIC • GRAVITY • MAGNETIC SURVEYS
Please mention GEOPHYSICS when answering advertisers

THE OFFICERS AND DIRECTORS OF

OFFSHORE EXPLORATION GROUP

INCORPORATED

ARE PLEASED TO ANNOUNCE ITS ORGANIZATION TO SPECIALIZE IN
OFFSHORE SEISMIC EXPLORATION OF THE HIGHEST ACCURACY AND QUALITY

JOHN W. FLUDE
President

EDGAR R. LOCKE
Vice President

THOMAS GARTH
Secretary-Treasurer

A. L. LADNER
Apache Exploration Company

G. A. BERG
Berg Geophysical Company

T. I. HARKINS
Independent Exploration Company

C. C. ZIMMERMAN
Keystone Exploration Company

ROBERT H. RAY
Robert H. Ray Company

SAM D. ROGERS
Rogers Geophysical Company

W. H. TAYLOR
Taylor Exploration Company

D. F. BROUSSARD

LINDEN 7666

3625 WESTHEIMER ROAD

HOUSTON 6, TEXAS

Still available . . .

INDEX OF WELLS SHOT FOR VELOCITY

a publication of

SOCIETY OF EXPLORATION GEOPHYSICISTS

To improve the usefulness of the "Index of Wells Shot for Velocity" by B. G. Swan, the Society has combined into a single list the original and three supplements published in *Geophysics.* Through the cooperation of owners, sponsors, operators, and well shooting associations the Index has been brought up to date.

A COMPLETE NEW INDEX WILL BE PUBLISHED EACH YEAR

PRICE (Estimated cost) $2.50 per copy

Postpaid in U.S.A.

Order copies for all your supervisors and party chiefs now

from

SOCIETY OF EXPLORATION GEOPHYSICISTS
624 S. Cheyenne Tulsa 3, Oklahoma

Ahead of the play

To KEEP AHEAD of the play, modern oil prospectors are using AERO reconnaissance methods. With the aerial mapping camera, they get an advance look at surface geology. The sensitive airborne magnetometer swiftly records significant sub-surface data on regional trends and basement structures. They can move into a new promising area with some foreknowledge, placing their leases before land prices have matured at high levels.

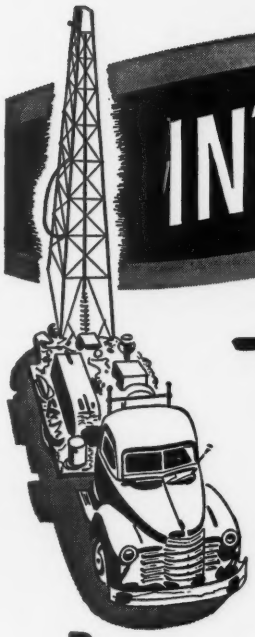
AERO has flown over half a million miles of oil reconnaissance over land and water. The savings we have effected for major oil companies by quickly delivering dependable reconnaissance facts are substantial.

No region is too remote—no terrain too formidable for AERO crews. They're at work now in the Middle East, South America, Canada, Africa and at home. Let us discuss your exploration or mapping problem now.

AIRBORNE MAGNETOMETER SURVEYS
PRECISE AERIAL MOSAICS
SHORAN MAPPING
PLANIMETRIC MAPS
TOPOGRAPHIC MAPS
RELIEF MODELS

AERO SERVICE CORPORATION
PHILADELPHIA 20, PA. . . . *Oldest Flying Corporation in the world*
CANADIAN AERO SERVICE, LTD., *Ottawa, is our affiliate*

Please mention GEOPHYSICS when answering advertisers



INTERPRETATION-

The Vital Step

BETWEEN SHOT-HOLE AND DRILL-HOLE

Reliable's interpretations are based on the clear, definite character data obtained from Reliable Seismograms. Experience and very close supervision mark each step. The precision of Reliable's instruments, based on years of laboratory and field testing, in the hands of experienced crews who work under the direct supervision of one of the partners, is your assurance of high quality work.

Reliable's 32-trace seismograms, 16-traces simple and 16-traces mixed, are now clearest obtainable. The experience and skill necessary for the best operation of these instruments is part of our service to you. You can depend on the close personal supervision and interpretation which you get from Reliable.

Write for the availability of crews. Assure yourself of a job well done.

SUPERIOR INSTRUMENTS
EXPERIENCED CREWS
VERY CLOSE SUPERVISION

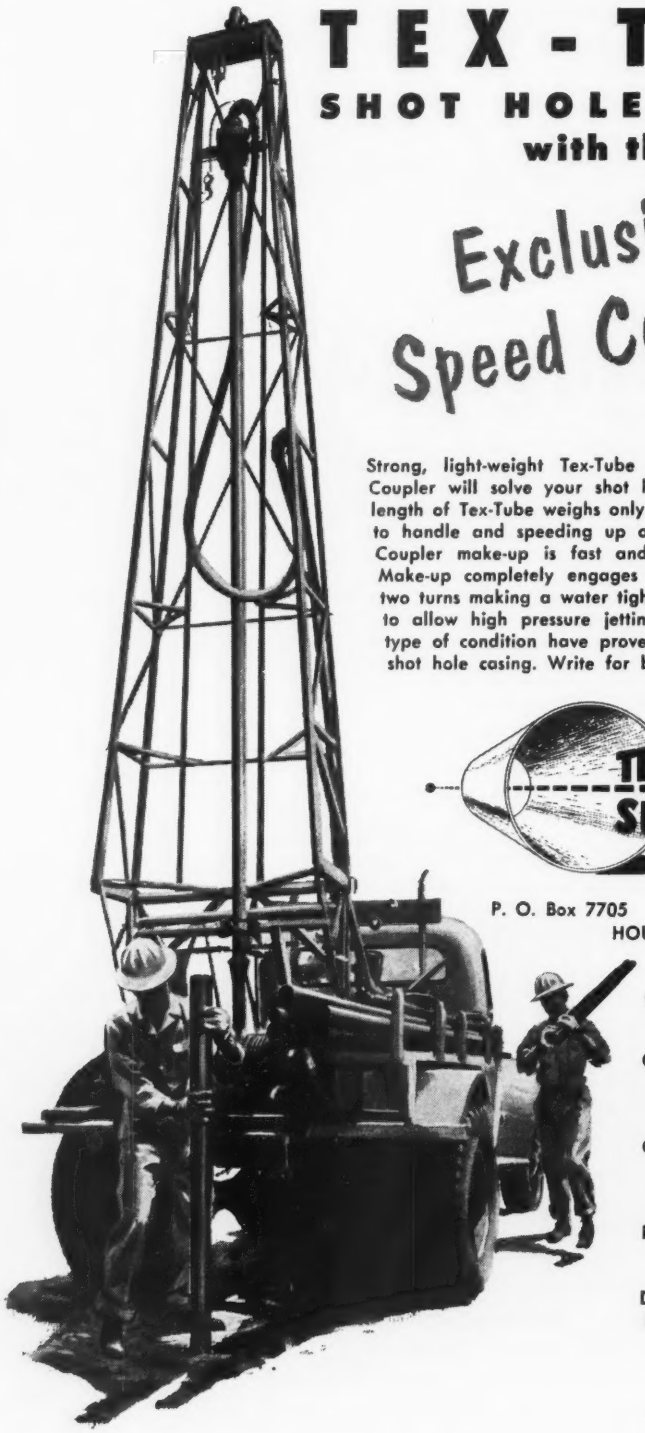
Reliable

GEOPHYSICAL CO.

Perry R. Love

Phone 108 Yoakum, Texas P. O. Box 450

TEX-TUBE
SHOT HOLE CASING
with the
Exclusive Speed Coupler



Strong, light-weight Tex-Tube with the exclusive Speed Coupler will solve your shot hole casing problems. Each length of Tex-Tube weighs only 20 pounds, making it easy to handle and speeding up operations. With the Speed Coupler make-up is fast and no collars are required. Make-up completely engages the three threads in only two turns making a water tight connection strong enough to allow high pressure jetting. Field tests under every type of condition have proved Tex-Tube to be the best shot hole casing. Write for bulletin today.

TEX-TUBE SUPPLY

P. O. Box 7705 CH arter 6411
HOUSTON, TEXAS

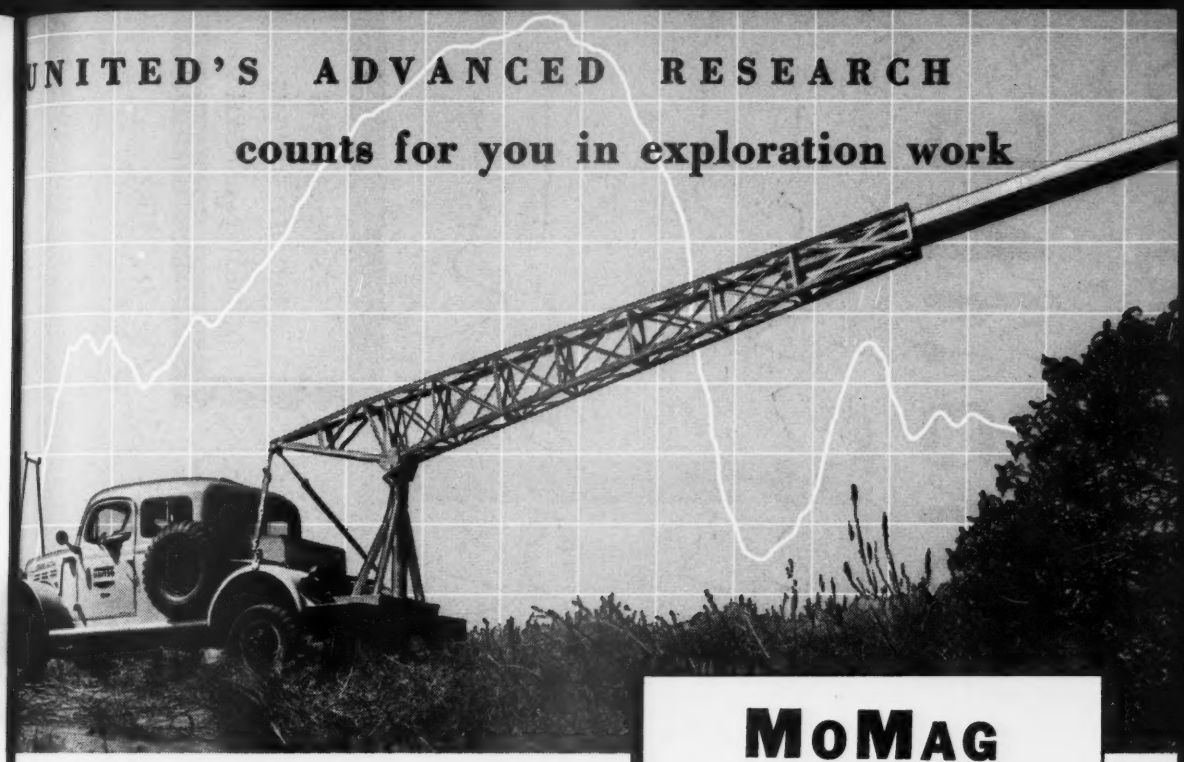
CORPUS CHRISTI
Phone 2-8141

OKLAHOMA CITY
Deupree Dist. Co.
Phone JAckson 8-6740

OKLAHOMA CITY
Grove Hardware Co.
Phone JAckson 8-4886

BATON ROUGE
Phone 5-1430

DIXIE DYNAMITE
DISTRIBUTORS, INC.
Alexandria, Houma, La.
Hattiesburg, Miss.
Brewton, Ala.



MoMag

United's New Continuous Recording Total Intensity Mobile Magnetometer.

United serves both the mining and petroleum industries.

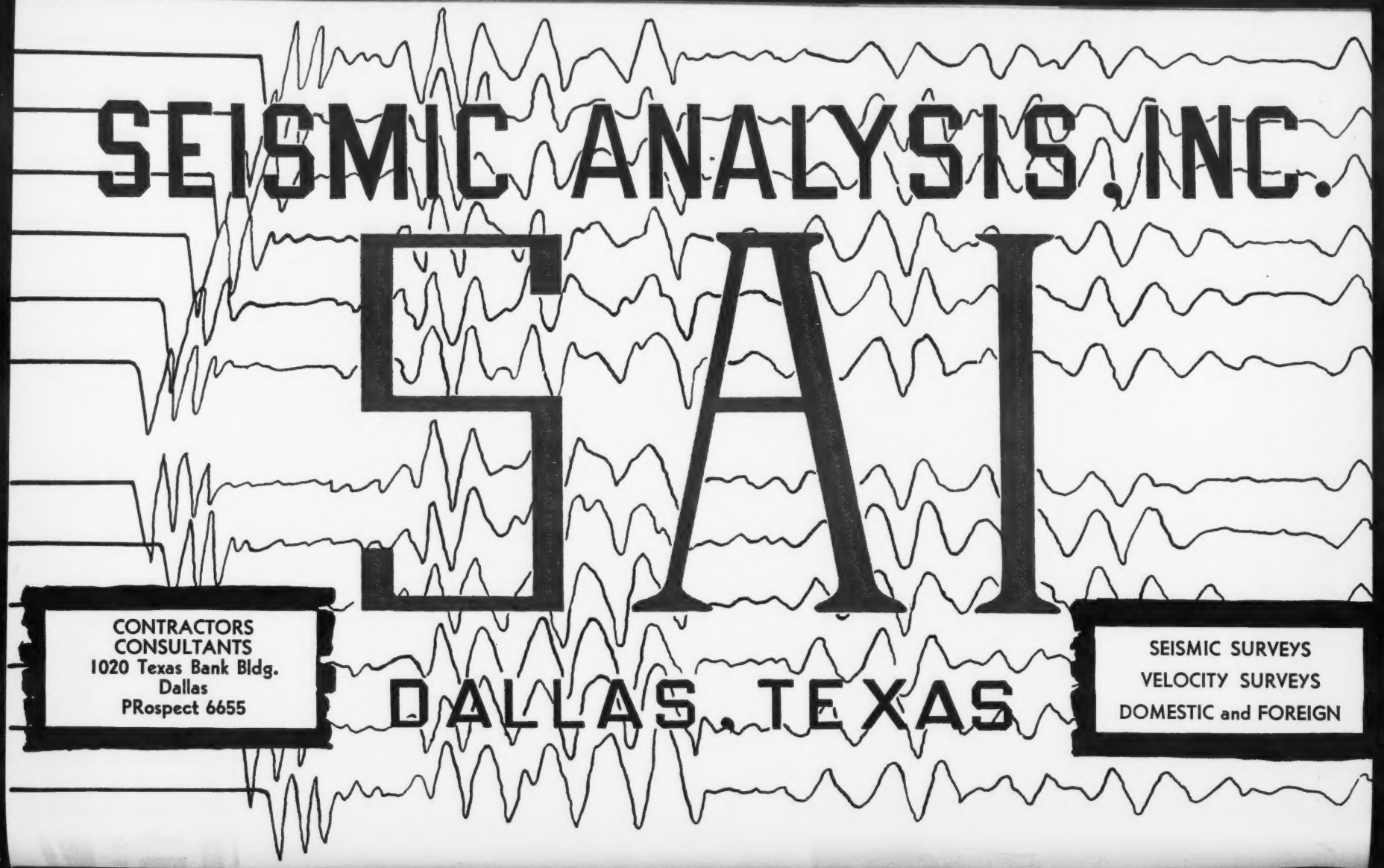
UNITED

Geophysical Company

SEISMOGRAPH • GRAVIMETER • MAGNETOMETER

P. O. BOX M, 1200 SOUTH MARENGO AVENUE
PASADENA 15, CALIFORNIA
1554 California Street, DENVER 2, COLORADO
1430 No. Rice Ave., HOUSTON, TEXAS
531 Eighth Avenue West, CALGARY, ALBERTA, CANADA
Apartado 1085, CARACAS, VENEZUELA
Rua Uruguaiana 118 - 9º Andar, RIO DE JANEIRO, BRAZIL

UNITED
EOPHYSICAL


SEISMIC ANALYSIS, INC.
SAI
DALLAS, TEXAS
CONTRACTORS
CONSULTANTS
1020 Texas Bank Bldg.
Dallas
PRospect 6655
SEISMIC SURVEYS
VELOCITY SURVEYS
DOMESTIC and FOREIGN

Seismograph

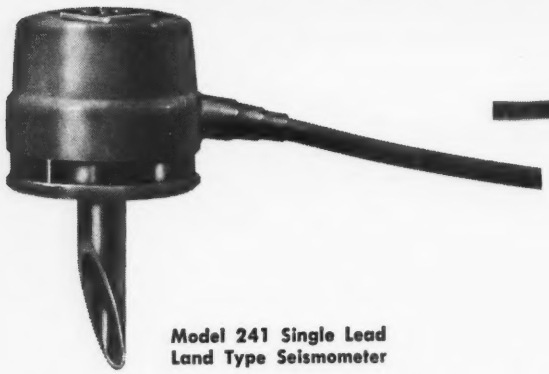
CABLES

and cable accessories

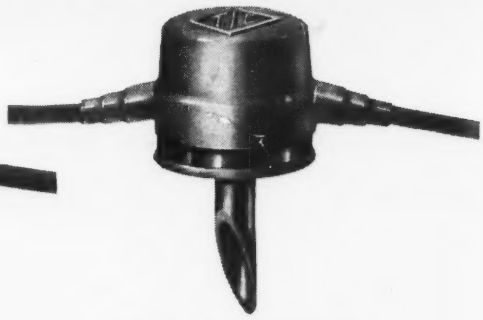
WRITE FOR COMPLETE ILLUSTRATED CATALOG

Vector MANUFACTURING COMPANY

5616 Lawndale · Houston 23 · Texas



Model 241 Single Lead
Land Type Seismometer



Model 241 Double Lead
Land Type Seismometer

TECHNICAL INSTRUMENT COMPANY OFFERS SEISMOMETERS FOR EVERY PURPOSE

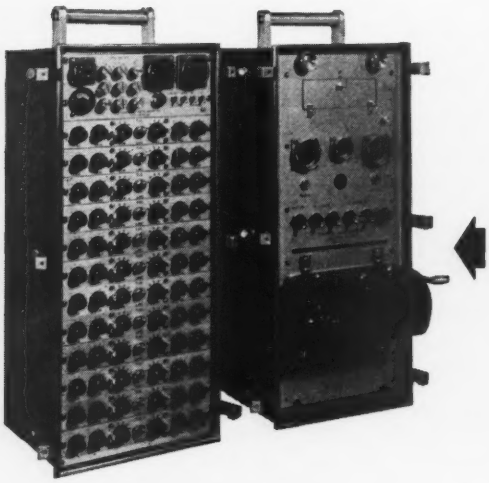
The Model 241, having been in production for over two years, and with thousands in service, has time proven its superior design. By utilizing the conventional two spring suspension, the units are extremely rugged, and their response to lateral accelerations is practically eliminated. On a weight-versus-output comparison, the Model 241 is still the most efficient seismometer on the market today.

The power output of a 7 ounce assembly into a matched load is 5.6 × 10-4 watts per (inch/second)^2. The open circuit voltage sensitivity of the standard 300 ohm coil is 0.82 volts/inch/second.

TECHNICAL INSTRUMENT COMPANY LAND TYPE SEISMOMETERS ARE RUGGED, DEPENDABLE, AND FEATURE UNUSUAL OUTPUT FOR SIZE. These units feature a newly designed plastic case, offering the utmost protection against sharp shock and abrasion. The lead outlets are near the bottom of the case and thus almost eliminate susceptibility to wind noise.

This design makes it possible to use two conductor "Copperweld" wire in a ¼" O.D. low temperature plastic jacket. This cable is rated by the manufacturer at 190 lbs. breaking strength. This extremely strong cable is sufficiently secured to the phone, so that the breaking point of the cable must be exceeded in order to pull the lead out of the phone. These superior phones are available as singles or cabled in multiple groups.

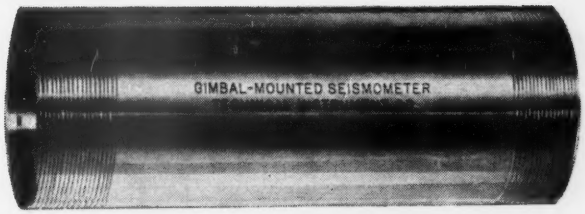
Destruction tests of the seismometer, lead and jacket indicate a trouble-free service in excess of three years.

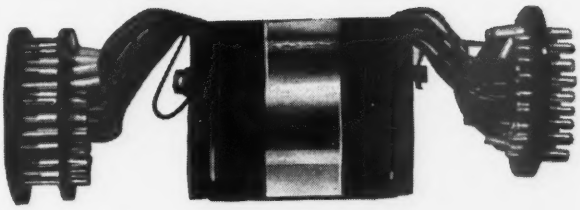


Dual Purpose Seismograph RECORDING INSTRUMENTS

For any and all of your seismograph instrument requirements you can depend on TIC instruments to give you outstanding dependability and results.

Write or call us for a field demonstration and further information on our latest model time-proven seismic recording instruments.





(above) Model 241 Gimbal Mounted Seismometer

A light weight, in-line detector for offshore operations

This unit is only 8" long and 2¾" O.D. It weighs only 5½ lbs., yet it has all the features of larger units. Gimbal action is accomplished through the use of heavy-duty precision, preloaded ball bearings. Excessive movement of the Gimbal element is limited by the presence of special damping fluid. The end threads fit the standard Vector Model 5210 bell and nut.

(right) Model 241-53 Marsh Seismometer

An extremely small and light weight instrument, weight 20 ounces, size 1½" O.D. × 6" long, the Model 241-53 was designed to be used either in swamp, marsh or adjacent land areas.

Due to its light weight and slim size this unique seismometer now makes it possible to use multiple plants and hence obtain usable records in certain previously considered NR (no record) swamp and marsh areas.

write or call us TODAY for complete information

Technical Instrument Co.

3732 WESTHEIMER HOUSTON, TEXAS

Southern Seismic Surveys

PRODUCE RESULTS THROUGH EXPERIENCE

Southern
GEOPHYSICAL
COMPANY

CENTRAL OFFICE
6640 Camp Bowie Blvd., Fort Worth, Texas

SIDON HARRIS
President

R. H. DANA
Executive Vice-President

G. J. LONG
Vice-President

MIDLAND **FORT WORTH** **DENVER**

WHAT ARE YOU LOOKING FOR?

We've Helped a Lot of Oil Companies and Individual Operators Locate "pay dirt" in a lot of places.

FOR

Gravity and Magnetic Surveys

SEE

E.V. McCOLLUM & CO.
WE WEIGH THE EARTH

E. V. McCOLLUM

515 Thompson Bldg.

FOR

Seismic Surveys and Interpretations

SEE

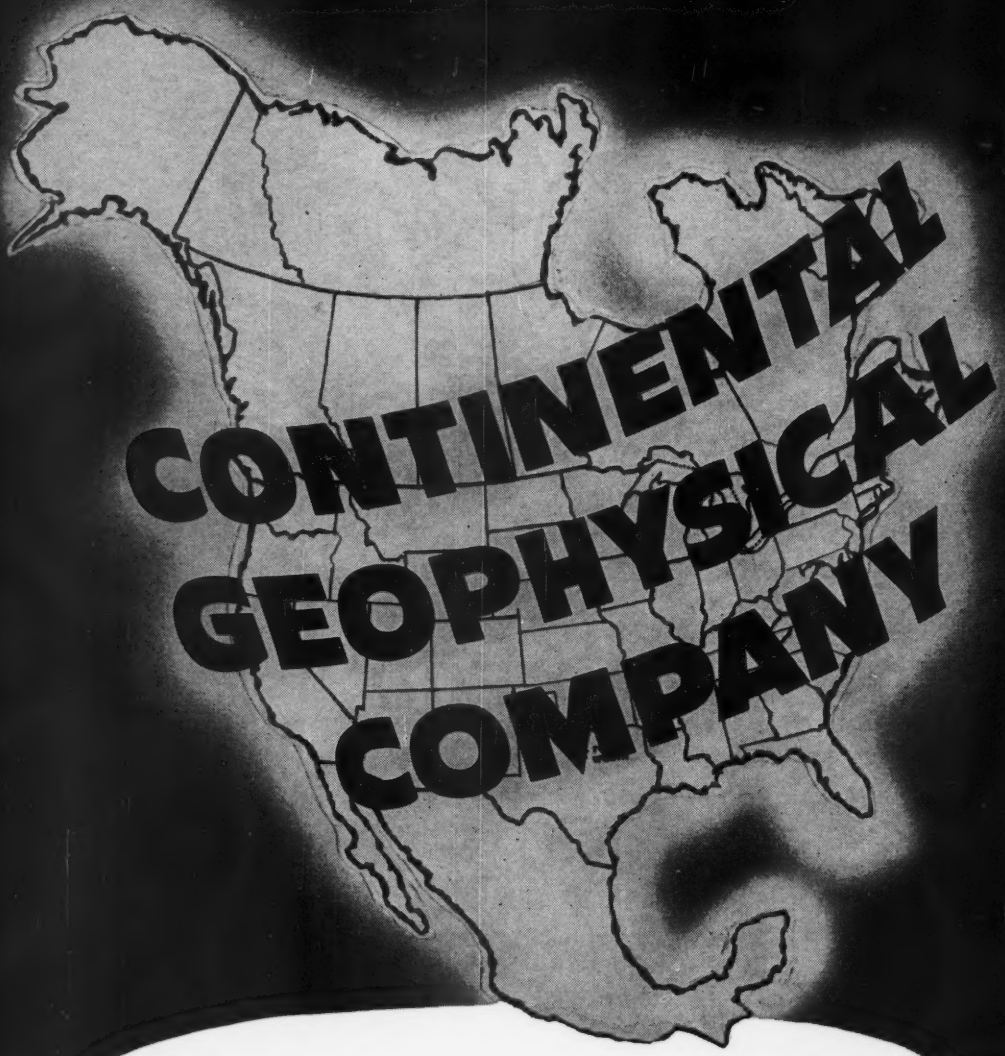
GEOSEIS INC.

CRAIG FERRIS

Phone 2-3149

TULSA, OKLAHOMA

CONTRACT SEISMOGRAPH SURVEYS*
SEISMIC REANALYSIS



C. J. LOMAX A. E. "Sandy" McKAY
602 CONTINENTAL LIFE BUILDING
FORT WORTH 2, TEXAS Telephone FAnnin 9231

MIDLAND DIVISION:
C. N. PAGE
500 W. HOLMSLEY ST.
Telephone 2-4245

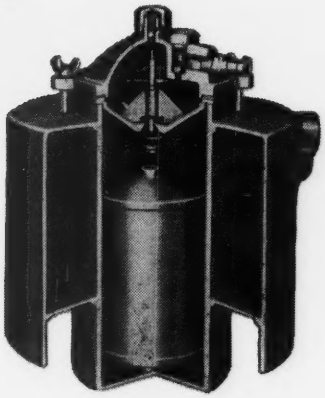
National Geophysical Company's
Latest Electronic Instruments

GRIFFIN builds field-tested equipment

- Water Trucks
- Explosive Trucks
- Hole Loading Machines
- Power Reel Line Trucks
- Recording Truck Bodies
- Portable Slush Pits
- Instrument Cabinets and Boxes
- Exhaust Diverters
- Portable Dynamite Storage Magazines
- Portable Cap Storage Magazines
- Skid Mounted Tanks
- Surveying Equipment
- Portable Tool Houses
- Vacuum Units
- Quick Opening Tank Valves
- Suction Hose Screens

Write for our new illustrated catalog

All Griffin equipment has been tested and perfected under field conditions, working closely with field personnel. We specialize in manufacturing to customer's design and specifications. Quotations on request — Domestic, Foreign.



Vacuum Unit — for use in filling water tank. Eliminates need for pump. One of many specially designed units by Griffin.

SUPPLIES & REPLACEMENTS

- Tank Fittings
- Ever-Tite Hose Couplings
- Rockwood Valves
- American Wire Rope
- Ramsey Winches
- Suction Hose
- Water Cans
- Power Take-offs
- Clearance Lights
- Mirro Flares
- Tail Chains
- Fire Extinguishers
- Snatch Blocks
- Hydraulic Jacks
- First Aid Kits
- Axes
- Loading Poles
- Shearing and forming steel

— Etc. —

GRIFFIN TANK & WELDING SERVICE

Phone: RIverside 6811

3031 Elm Street — Dallas 1, Texas

COMPLETE GEOPHYSICAL SERVICE

- **SEISMIC SURVEYS**
- **GRAVITY SURVEYS**
- **MAGNETIC SURVEYS**
- **REVIEW ANALYSIS**

Experienced States Exploration contract crews offer complete, integrated geophysical service . . . using the most advanced equipment, specifically designed for dependable service under any operating conditions . . . properly used with skill and knowledge for the greatest assurance of positive results.

Direct scientific supervision over field activity and analysis on every project assures you of a job well done. Phone or write for complete details on States Exploration Service, without obligation.

States EXPLORATION COMPANY

SEISMIC • GRAVITY • MAGNETIC SURVEYS

Hubert L. Schiflett
P.O. Box 845
Phone 2544
Sherman, Texas

•

PARTNERS

•

John W. Byers
709 M & M Building
Phone BLackstone 0213
Houston, Texas

Please mention GEOPHYSICS when answering advertisers

SSC's KANSAS DISTRICT OFFICE

The Kansas portion of the Anadarko Basin appears to contain reserves of oil and gas which have been barely touched.

In Kansas SSC crews have been continuously engaged in prospecting for petroleum since 1932 where they have since accrued more than 450 crew-months of seismic exploration experience.

The methods and techniques employed by SSC's Kansas District Office personnel are based on this long experience.

For information concerning seismic or gravity contract rates and crew availabilities, contact SSC's District Office in Wichita.

Write or phone Seismograph Service Corporation

108 Koch Building
Telephones 2-6437
Wichita, Kansas

Seismograph Service Corporation

Seismic Surveys — Gravity Surveys — Pilot Crews — Lorac

TULSA 1, OKLAHOMA, U.S.A.

World-wide Experience

look AT THE RECORD!

Here is the way GSI Field Service serves YOU!

Properly functioning seismic equipment is a key to *more useful data.* GSI's instrument test program makes sure that GSI field party equipment maintains its built-in accuracy. GSI Field Service engineers regularly visit field parties to check operation and maintenance of instruments under work conditions. They supplement on-the-spot checks with careful study of weekly and monthly test records from field parties. They keep "on top" of GSI instruments . . . help the party chief make certain his equipment continues efficient production of top quality data.

More benefits to you when you contract with GSI: *GSI Field Service also recommends correct equipment to survey your prospect; provides trouble-shooting service to GSI field parties anywhere; engineers methods and equipment to overcome unusual field problems. Write for booklet, "GSI Instrument Field Tests". It outlines GSI field party procedure in regular instrument checks. It shows another way GSI helps you in* ***FINDING A WORLD OF OIL.***

GSI

GEOPHYSICAL SERVICE INC.

5900 LEMMON AVENUE • DALLAS 9, TEXAS